CHAPTER 2

TRANSDUCERS

Section I. Carlson Type Transducers

2-1. Description of the Instruments. Since the Carlson transducers have been so universally accepted for use in concrete structures, these transducers will be considered separately. The Carlson transducers utilize two different electromechanical principles, namely changes in wire tension cause change in the electrical resistance of the wire, and also changes in the temperature of the wire cause change in its electrical resistance. The strain meter, joint meter, stress meter, pore pressure cell, and the reinforced concrete (R-C) meter utilize both principles to measure deformation and temperature changes. In the resistance thermometer temperature changes are measured by means of resistance changes of copper wire.

2-2. Strain Meter.

a. Operating Principle. The standard Carlson strain meter can be embedded in concrete or attached to a surface with saddle mounts. It measures change in length (strain) and temperature with the help of a simple Wheatstone-bridge test set or the Carlson Test Set. The meter, Figure 2-1, contains two coils of highly elastic steel wire, one of which increases in length and electrical resistance when a strain occurs, while the other decreases. The ratio of the two resistances is independent of temperature (except for thermal expansion) and, therefore, the change in resistance ratio is a measure of strain. The total resistance is independent of strain since one coil increases while the other decreases the same amount due to the change in length of the meter. Therefore, the total resistance is a measure of temperature.

b. Lengths and Features. The standard strain meter is furnished in three different lengths, from 8 to 20 in., but all have identical sensing elements (Table 2-1). The meter has a 1/4-28 SAE tapped hole in the end plug opposite the cable end to permit attachment to a spider for mass concrete embedment, or for adding an extender to increase the length and sensitivity. The body is covered with PVC sleeving to break the bond with the concrete.

c. Temperature Correction. The frame of the meter is all steel, making the temperature correction for thermal expansion of the frame 6.7 microstrains per degree F. This value is nearly the same as the thermal expansion of the concrete making only a small temperature correction necessary due to the change in length of the frame due to temperature change.

CARLSON ELASTIC WIRE STRAIN METER

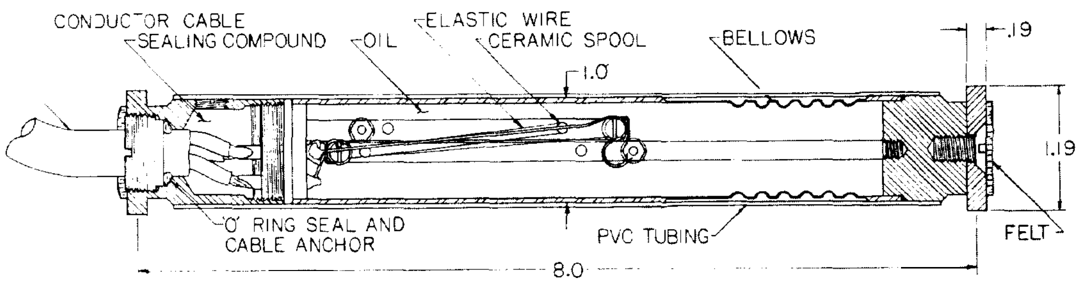


Figure 2-1. Carlson Elastic Wire Strain Meter (Courtesy of Carlson Instruments)

Table 2-1

SPECIFICATIONS - "A" SERIES, CARLSON STRAIN METER

Model Number	A8	A10	A10S[b]	A20
Range, micro-strain[a]	2600	2100	2100	1050
Least reading, micro-strain, max.	3.6	2.9	2.9	1.5
Least reading, temperature, °F	0.1	0.1	0.1	0.1
Gage length, in.	8	10	10	20
Weight, lb	.8	1.3	1.3	1.8

[a] Normally set at factory for 2/3 range in compression. Within limits, other settings may be specified.

[b] Saddle mount. Mounting diameter is l-1/16 in.

2-3. <u>Miniature Strain Meter.</u> The miniature meter (Figure 2-2) is for embedment in concrete where small size and economy are essential. The principle of operation is basically the same as the standard strain meter. A feature of the miniature meter is that the basic 4-in. meter can be extended to greater lengths by removing the end flange and adding an extender without disturbing the sensing element, thus increasing its sensitivity (Table 2-2). The body of the meter is covered with PVC tubing to break the-bond to the concrete. The conductor cable for the strain meter is 3 - conductor No. 22 AWG shielded with PVC insulation.

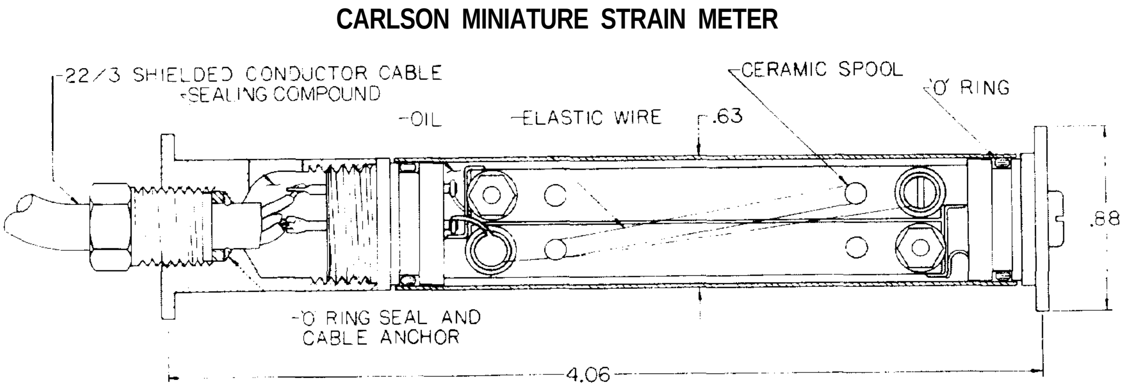


Figure 2-2. Carlson Miniature Strain Meter. (Courtesy of Carlson Instruments)

Table 2-2

SPECIFICATIONS - M SERIES, CARLSON MINIATURE STRAIN METER

Model Number	M4	M8	M10
Range, micro-strain[a]	3900	2000	1600
Least reading, micro-strain	5.8	2.9	2.3
Least reading, temperature, °F	.1	.1	.1
Gage length, in.	4.062	8	10
Weight, lb	.19	.54	.71

[a] Normally set at factory for 2/3 to 3/4 of range in compression. If specified, range may be divided equally between compression and expansion.

2-4. Joint Meter.

a. Operating Principle. The Carlson joint meter, Figure 2-3, is similar to the strain meter except that it has a greater range. This is accomplished by having a coil spring in series with each of two loops of elastic wire. The joint meter is used mainly to measure the opening-of joints, and therefore, it has most of its range in expansion (Table 2-3). It measures temperature as well as expansion or contraction in the same way as the strain meter does.

b. Lengths and Features. The dimensions of the joint meter are about the same as those of the strain meter. A bellows near the center of the length permits movement to be transmitted to the interior wires. The bellows has a bursting pressure of 400 psi, but should normally not be exposed to more than 100 psi hydraulic pressure. Polyolefin heat-shrinkable tubing is placed over the bellows to prevent bonding or jamming by concrete or mud.

c. Installation Sockets. The installation of joint meters is facilitated by embedding a steel socket on one side of the joint, and not inserting the joint meter until just before placing the concrete on the second side. However, the joint meter can be ordered with or without sockets.

CARLSON JOINT METERS AND FOUNDATION METERS

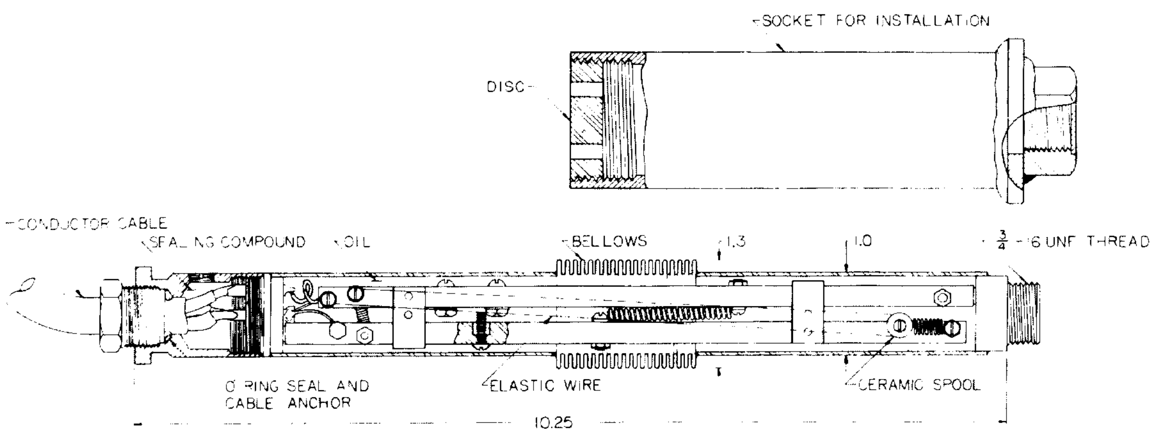


Figure 2-3. Carlson Joint and Foundation Meter. (Courtesy of Carlson Instruments)

Table 2-3
(Courtesy of Carlson Instruments)
SPECIFICATIONS - J & F SERIES,
CARLSON JOINT AND FOUNDATION METERS

Model Number	JO.1[a]	J0.25[a]	J0.5[a]	F0.1[b]	F0.25[b]	F0.5[b]
Range						
Contraction, in.	.02	.01	0.1	.08	.24	0.4
Expansion, in.	.08	.24	0.4	.02	.01	0.1
Least Reading						
Strain, in.	.0002	.0005	.001	.0002	.0005	.001
Temperature, °F	.1	.1	.1	.1	.1	.1
Weight, lb	1.2	1.2	1.2	1.2	1.2	1.2
Resistance, ohms [c]	64	64	64	64	64	64

[a] Designed for expansion.

[b] Designed for contraction.

[c] Approximate resistance for two coils at room temperature.

2-5. Stress Meter for Concrete.

a. Description. The Carlson Concrete Stress Meter (Figure 2-4) is designed for embedment in concrete to measure compressive stress in concrete independent of shrinkage, expansion, creep, or changes in the modulus of elasticity of the concrete. The Stress Meter is designed to simulate as nearly as practicable a thin plate with a finite modulus of elasticity.

b. Principle of Operation. The meter consists essentially of a 7-in. diameter plate with a strain meter sensing element mounted on one face. The plate has a mercury film at its midthickness and a flexible rim with the result that any stress through the plate is applied to the mercury film. The mercury is in contact with the more flexible center portion and deflects it elastically in direct proportion to the intensity of stress. The measuring unit is a small, elastic, wire strain meter as described in paragraph 2-2, again measuring the temperature along with stress. The sensing element is isolated from the concrete by being protected by a metal shield tube covered with PVC tubing.

c. Installation Considerations. Since the design of the stress meter requires that the modulus of elasticity of the plate through its thickness be not less than half that of the concrete around it, (Table 2-4), it is essential that it be in intimate contact with the concrete after embedment. Poor contact would be equivalent to a low modulus of elasticity. Whenever possible, the C800 stress meter with a range of 800 psi should be used in preference to others because this combines the most favorable design characteristics.

CARLSON STRESS METER FOR CONCRETE

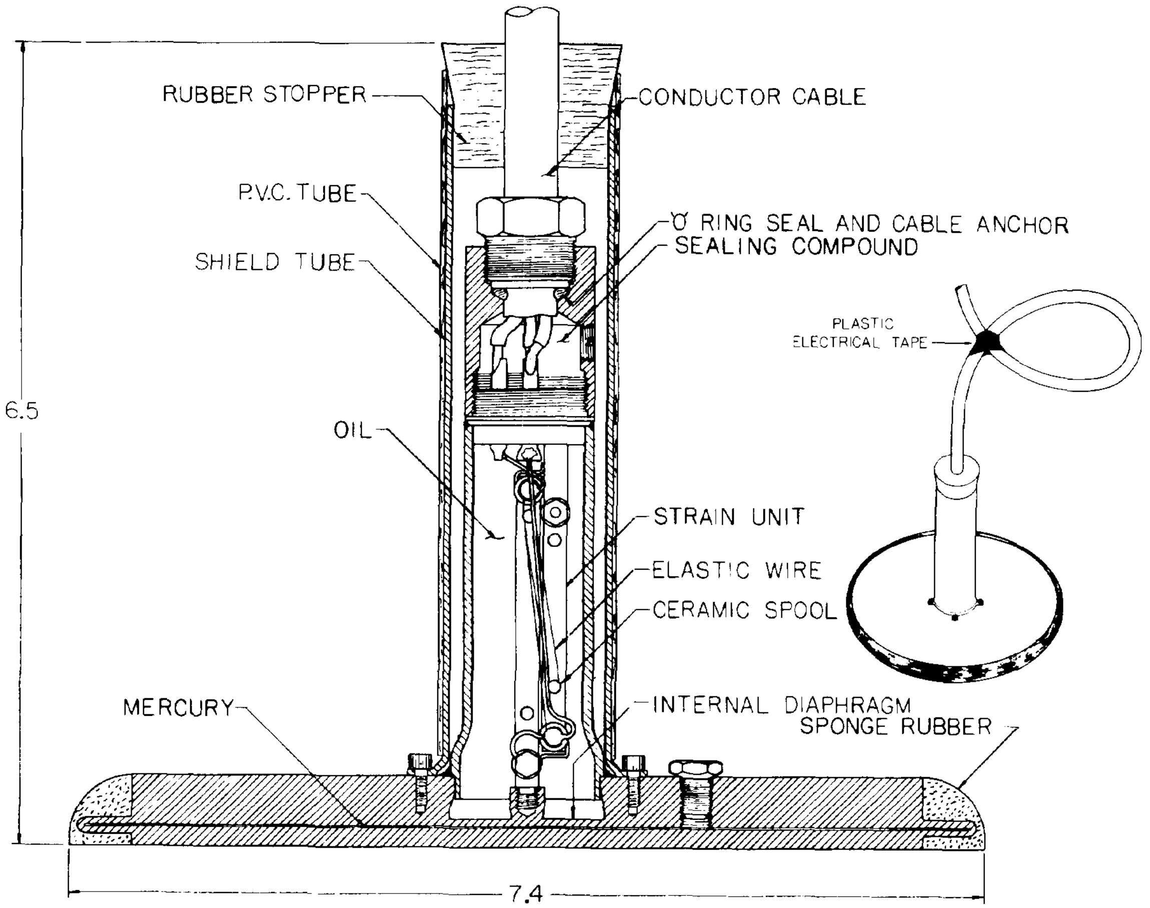


Figure 2-4. Carlson Stress Meter. (Courtesy of Carlson Instruments)

Table 2-4
(Courtesy of Carlson Instruments)
SPECIFICATIONS - C SERIES, CARLSON CONCRETE STRESS METER

Model Number	C400	C800	C1500
Range, psi[a]	400	800	1500
Least reading, psi	3	5	10 Least
Least reading, temperature, °F	.1	.1	.1
Modulus of elasticity, psi	$2x10^6$	$4x10^6$	$6x10^6$
Effective area of meter, sq in.	35	35	35
Weight, lb	6.7	6.7	6.7

[a] Higher ranges are available upon special order.

2-6. Pore Pressure Cell. The Carlson Pore Pressure Cell (Figure 2-5) is designed to measure the pressure in the pores of any porous material. It functions by allowing the water pressure to pass through a sintered stainless steel disk to an internal diaphragm while holding back the pressure due to other forces. The water pressure causes a very small deflection of the internal diaphragm. The deflection is measured with the same sensing element as used in the stress meters (paragraph 2-2). The same electrical resistance wires which sense the deflection of the diaphragm also sense the temperature. The conductor cable most commonly used is the same as for the stress meter and standard strain meter. The characteristics of the gage are given in Table 2-5.

Table 2-5
(Courtesy of Carlson Instruments)
SPECIFICATIONS - P SERIES, CARLSON PORE PRESSURE CELL

Model Number	P25	P50	P100	P200
Range, psi[a]	25	50	100	200
Least reading, psi	.1	.2	.4	.8
Least reading, temperature, °F	.1	.1	.1	.1
Weight, lb	2.25	2.25	2.25	2.25

[a] Special ranges may be ordered.

CARLSON PORE PRESSURE CELL

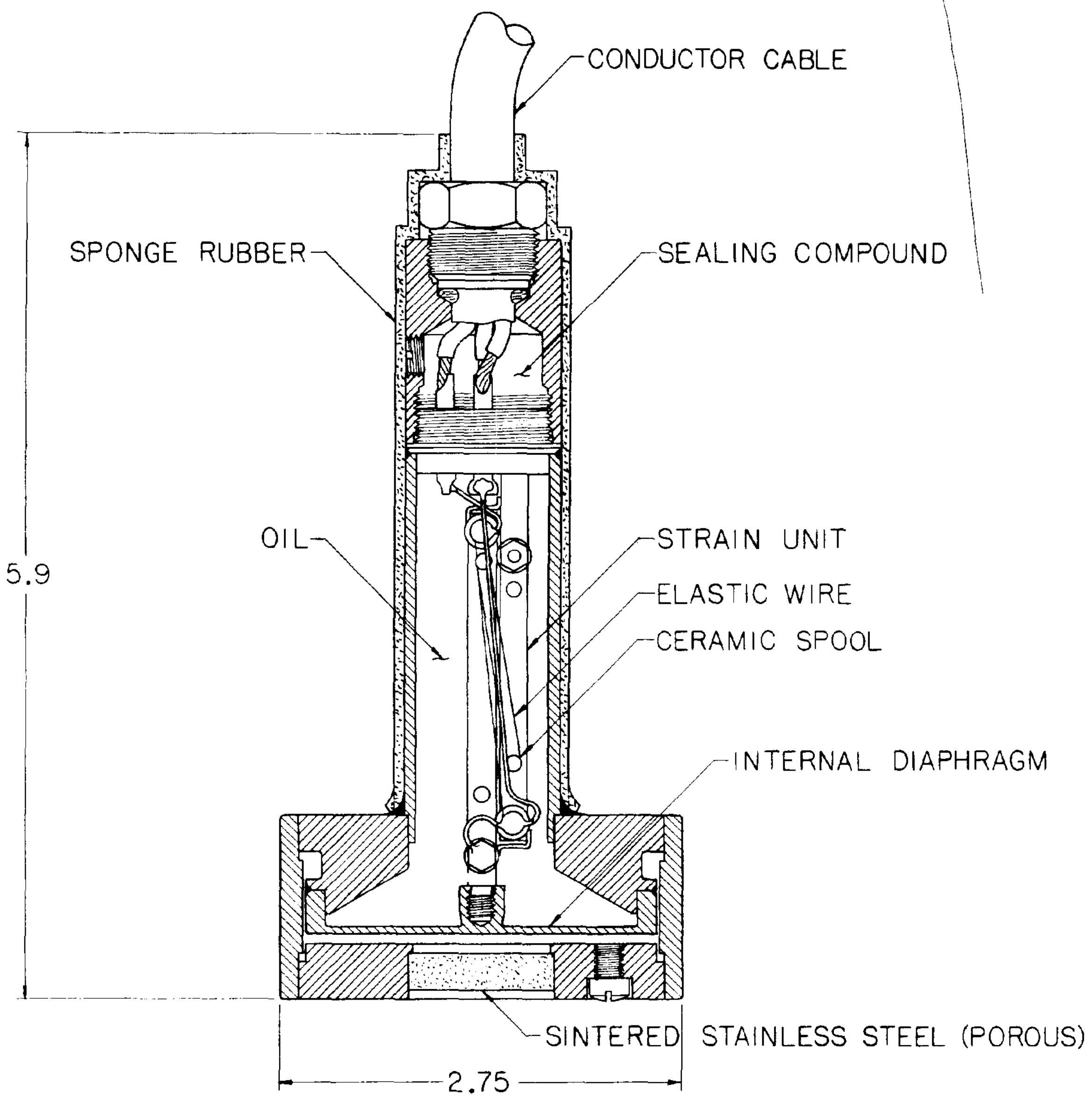
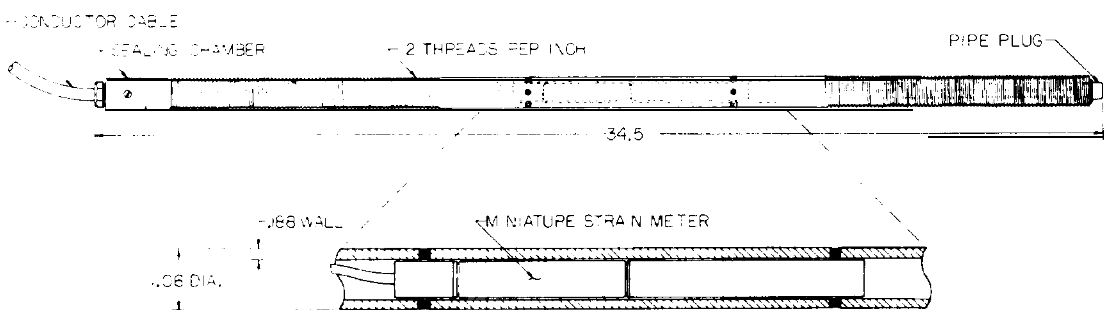


Figure 2-5. Carlson Pore Pressure Cell. (Courtesy of Carlson Instruments)

2-7. The Reinforced Concrete Meter. The reinforced concrete meter (R-C meter) is a device for measuring the strain behavior of reinforced concrete. It consists of a miniature strain meter encased in a 0.188-in.-thick hollow steel bar of 1.06-in. diameter (Figure 2-6). It is used for embedment in reinforced concrete and measures the average strain over the rods length. The rod is 34.5 in. in length and the ends of the rod are threaded to provide a bond surface to anchor the meter in the concrete.

a. Advantage. This gage measures the average length change. This is important in that it measures the stress as a function of the distance between threaded anchors at the end of the bar. Conventional strain meters of shorter length would indicate a different result depending upon whether a crack is within the gage length or just beyond it. Consequently, a strain reading in the meter larger than the strain capacity of the concrete is an indication of a tensile crack in the concrete. Also, when the strain is below the tensile strain capacity, the meter indicates both the tensile stress in the reinforcing and the strain in the concrete.

THE R-C (REINFORCED CONCRETE) METER



SPECIFICATIONS

Range (micro-strain)	# 950
Least Reading (micro-strain)	3.4
Least Reading, (stress in steel PSI)	100
Least Reading, temperature (°F)	0.1
Maximum Stress (PSI)	44,000
Weight (lbs.)	5.5

Figure 2-6. Reinforced Concrete Meter. (Courtesy of Carlson Instruments)

b. Installation. Since the sensing element is encased in a hollow steel chamber, the meter is quite rugged. It is most usually attached to the reinforcements by means of wires attached between the meter and the reinforcement at the meters ends. The cable lead from the meter should be attached to the reinforcement in such a way that it will not pull when the concrete is placed.

c. Temperature correction. The temperature correction can be applied simply and accurately because the R-C meter is also a thermometer, and the correction per degree is already a known factor.

2-8. Resistance Thermometer.

a. Description. The Carlson resistance thermometer (Figure 2-7) is especially designed and constructed for embedment in concrete. The resistance thermometer is simply a non-inductively-wound coil of enameled copper wire enclosed in a vinyl mastic cover. The wire is wound on an insulating spool in such a way that there will be no appreciable strain changes as the temperature changes. The thermometers have a uniform resistance of 39.00 ohms at 0°F and change 0.01 ohms per degree. The temperature range on the thermometer is 0°F to 180°F (Table 2-6).

CARLSON RESISTANCE THERMOMETER

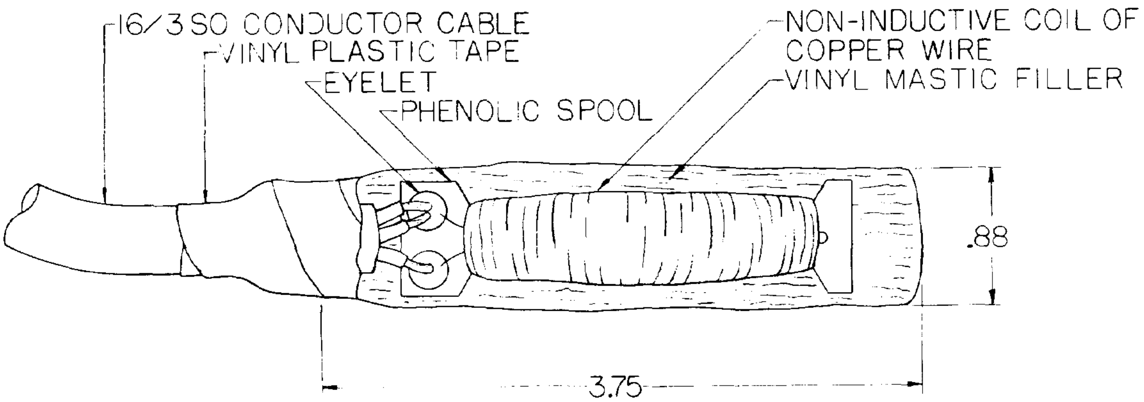


Figure 2-7. Resistance Thermometer. (Courtesy of Carlson Instruments)

Table 2-6
(Courtesy of Carlson Instruments)
SPECIFICATIONS - TF1,
CARLSON RESISTANCE THERMOMETER

Model Number	TF1
Range, °F[a]	0 to 180
Least reading, °F	0.10
Weight, lb	0.5

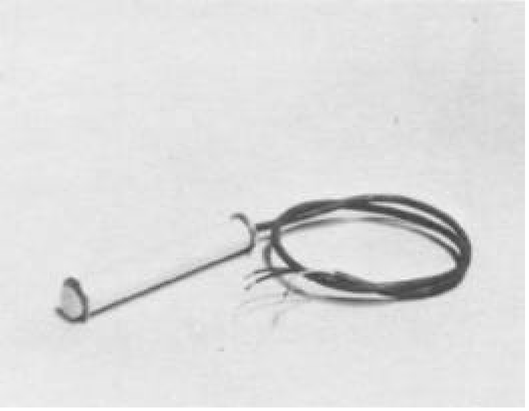
[a] Thermometers are trimmed to be within ± 0.5°F.

b. Conducting Cable. Each thermometer is supplied with 30 in. of three-conductor rubber-covered cable, size 16, Type SO. The three conductors make it possible for special test sets to make an automatic subtraction of the resistance of the leads by balancing one conductor against another in adjacent arms of the Wheatstone bridge circuit.

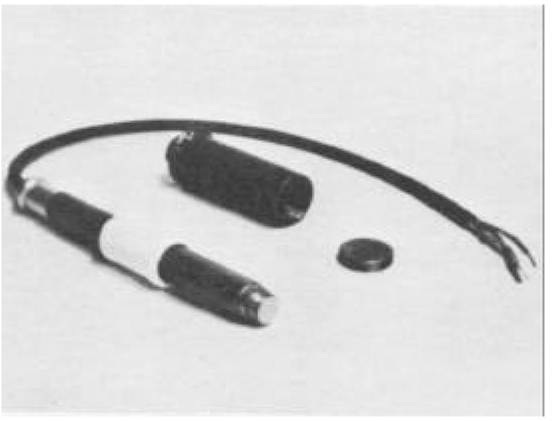
2-9. Source. The six resistive-type instruments previously described are shown on Figure 2-8. These instruments may be purchased from Carlson Instruments, 1190-c. Dell Avenue, Campbell, California, 95008.

2-10. Instrument Preparation.

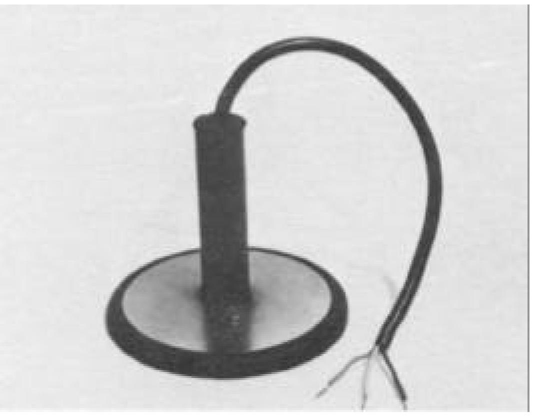
a. Receipt. Strain meters, joint meters, and resistance thermometers are carefully packed for shipment. Stress meters are shipped in specially designed cartons which in turn are placed in a double walled carton. Upon receipt of a shipment of instruments they should be unpacked, inspected for damage, and checked for operability. Strain meters and joint meters should be closely examined for oil leaks and all instruments should be read and the readings checked against calibration data furnished by the manufacturer. In the case of strain meters, stress meters, joint meters, and pore pressure cells the ratio should be very close to the neutral or no-load ratio given in the calibration data. Instruments which show oil leaks, are unreadable, or give obviously unreasonable readings, should be separated from the shipment and immediately returned to the manufacturer for repair or replacement.



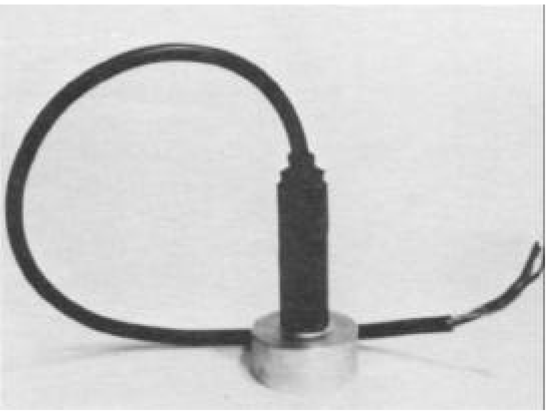
Strain Meter



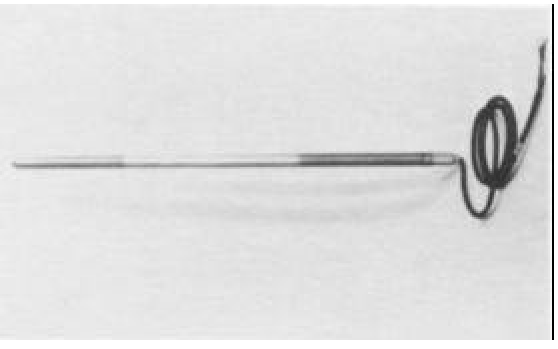
Joint Meter



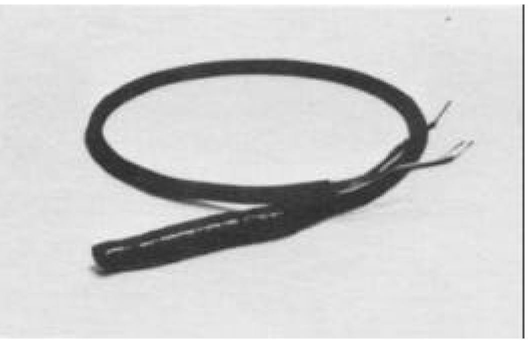
Stress Meter



Pore Pressure Cell



Reinforced Concrete Meter



Resistance Thermometer

Figure 2-8. Carlson Embedment Instruments (Courtesy of Carlson Instruments).

b. Instrument Storage and Protection. Stress meters and pore pressure cells should be left in packing boxes for storage as illustrated in Figure 2-9, secured as received. The inspection and reading check to be made as outlined above can be completed without removing the strips which secure the meters for shipment. For protection during cable splicing operations and handling on the job, strain meters and joint meters may be carefully repacked in the manner received or preferably each meter may be placed in a protective container such as shown in Figure 2-10. The container illustrated was made by cutting fiber conduit of appropriate size (about 2-1/2-in. id) into suitable lengths. The meters are loosely wrapped with waste cloth or rags and placed inside the container. Inside the container the instrument is surrounded with wrapping paper and some end packing so that it is held securely and cushioned against shock, which might damage it. The ends of the container are taped with friction or other suitable tape to hold the meter and the packing in place. No special protection is necessary for resistance thermometers.

c. Identification. Each meter should be identified by a letter prefix designating the type of instrument, and numbered consecutively for each type. Thermometers usually are given the prefix T, joint meters JM, strain meters SM, stress meters C, pore pressure cells PP, and reinforced concrete meters, RC. Those instruments which are installed for a special purpose, such as "no-stress" strain meters placed so as to be unaffected by stresses within the structure, should be further identified by a letter suffix, usually X. To facilitate identification of the instruments during the difficult and hurried operations accompanying placement each meter should be plainly marked by lettering its identification number on the temporary protective cardboard cover. Those instruments not provided with such protectors may be marked by fastening a large mailing tag, with the identification number lettered thereon, to the meter.

d. Cable Identification. When the cable lead is spliced or connected to a meter, a copper band with the instrument identification number stamped or punched on it is crimped to the cable about 3 ft from the meter and a similar band crimped about 1 ft from the free end of the cable. In addition, in case this latter metal band is stripped off during placement operations, a second marker consisting of the identification number marked on white tape, and covered with linen and friction tape, should be placed around the cable near the reading end.

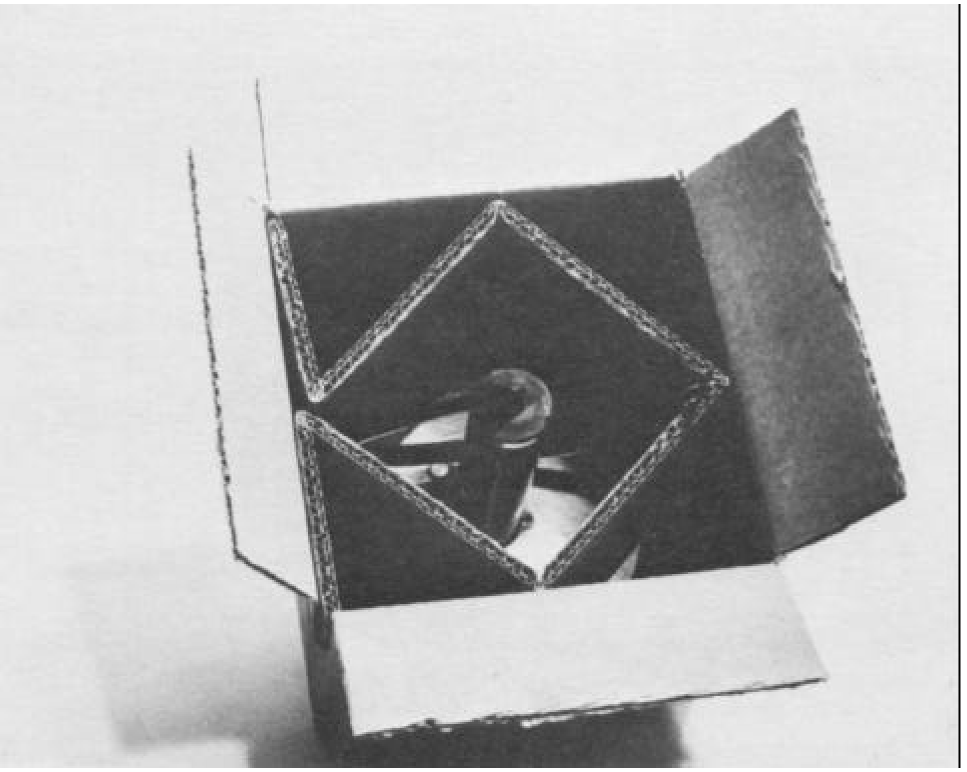


Figure 2-9. Stress Meter Packed for Shipment (Courtesy of Carlson Instruments).

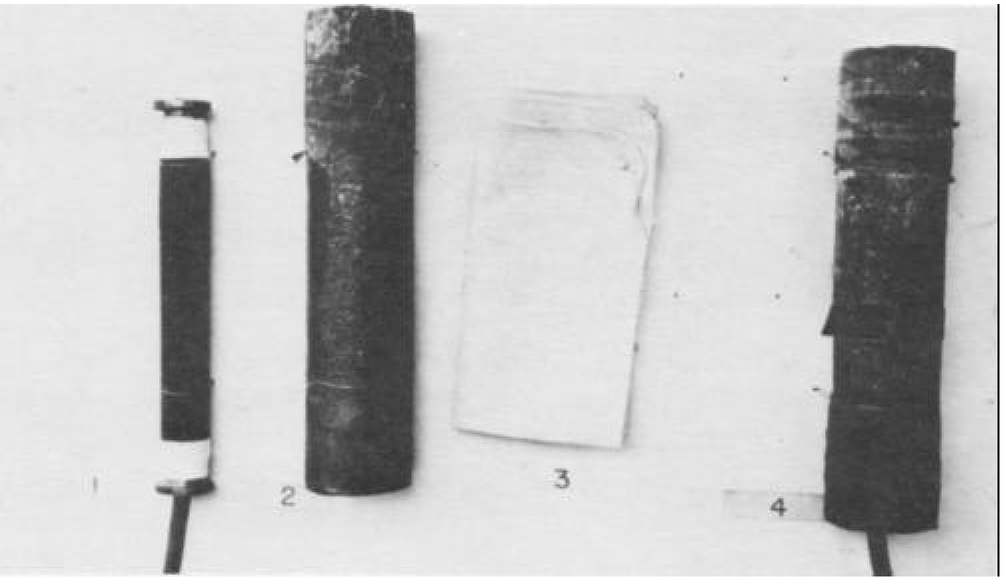


Figure 2-10. Strain Meter and Protecting Case (Courtesy of the Tennessee Valley Authority).

e. Alternate Identification. An alternative method of cable identification has been used by Walla Walla District. Two types of heat shrinking tubing are used. First, a white shrink-tubing is heat shrunk around the cable. Identification markings are made on this tubing with a Kingsly Wire Marking Machine. Secondly, for permanent protection, a clear type of tubing is heat shrunk over the white tubing containing the identification markings. Two tags are placed on each cable.

2-11. Waterproofing Treatment.

a. Method. Subsequent to being purchased each thermometer is given an additional waterproofing treatment consisting of coating the thermometer case and several inches of the attached cable lead with GE Cable Joint Compound No. 227. This is done by dipping the thermometer into a bucket of hot (325°-350°) melted joint compound, quickly removing it, and immediately immersing it in a bucket of cold water to prevent damage to the interior coils which might occur due to overheating. The coated meter is then wrapped with ordinary friction tape as protection to the coating during handling. While this additional treatment provides additional moisture-proofing, the coating also acts as undesirable thermal insulation. For this reason only those thermometers which are to be located more than 3 ft from any concrete surface (excluding walls, roofs, and floors of galleries and interior rooms or recesses) should be given the additional waterproofing treatment.

b. Exclusions. No coating should be applied to strain meters, stress meters, joint meters, and pore pressure cells, since the tape and joint compound would affect the bond with the concrete, and hence influence their response to stress or strain conditions.

2-12. Cable Leads.

a. Types. The Carlson meters are normally supplied with about 30 in. of No. 16 AWG three conductor, Type SO, neoprene rubber-covered cable. This size is used for cable runs of up to 600 ft; larger gage wire is used for longer runs. In most instances more cable will be needed than that supplied with the instrument. It is recommended that any type of cable splice be avoided when running these instruments from point of embedment to the terminal station in a gallery. Splices are viewed as sources of potential failure of embedded instruments and subject to deterioration that can disable the meter. To avoid field splicing, adequate cable lengths can be ordered with the instrument.

b. Cable Length. In estimating the length of cable to be added, a suitable route between the point of embedment of the instrument and the terminal station in the gallery is selected by study of the drawings. In selecting the route, due consideration must be given to the construction procedures involved in placing the concrete where the instrument is to be embedded and to possible obstructions along the chosen route. After the selected route has been verified the length of cable required is estimated, and a small amount (usually 10 percent or 5 ft, whichever is larger) is added to allow for extra length required due to normal variation from the selected route. This amount of cable should be ordered with the meter at the time of purchase.

c. Splicing Procedures. Although splicing cables onto meters is strongly discouraged, there are situations where splicing cannot be avoided. In these cases lead cable should be Type SO neoprene jacketed of appropriate gage and of three or four conductor as required. Field splicing can be accomplished by using the technique described in Appendix B.

2-13. Calibration Corrections.

a. Calibration Factors. Except for resistance thermometers, each instrument is individually calibrated by the manufacturer and calibration factors are furnished for all instruments. These factors are normally obtained from calibration runs, using short 2-or 3-ft leads, and calibration adjustments must be computed by the user to take into consideration the ballasting effect of the added cable leads when resistance ratios are involved in the instrument observations. The instrument characteristics furnished by the manufacturer should be recorded in a permanent file or ledger, together with the project identification number assigned to each meter and the results of the calibration correction measurements described herein. These records will prove invaluable later if necessary to trace some deviation in the readings, and also serve to detect improper splices or malfunctioning of the meter before it is installed. The calibration adjustments should be done by fully trained personnel. It is suggested that the individuals responsible for this work consult with either the manufacturer of the instruments or the USAE Waterways Experiment Station (WES) to assure that proper methods and equipment are used.

b. Strain Measuring Units. The transducer element in the strain meter, stress meter, joint meter, pore pressure cell, and the R-C meter is the basic elastic wire strain gage, requiring at least 3-conductor color coded cable, shown on the wiring diagrams (Plates 2-1 and 2-2). When 4-conductor cable is added, the fourth wire is connected to the white conductor during splicing operations.

c. Operation Check. In order to check the operation of the meter, establish resistance values of various parts of the electrical circuit for each instrument, and secure information for correcting or checking the given calibration factors, a series of direct resistance observations (Plate No. 2-3) is made in the shop by means of a Wheatstone bridge or portable test set.

(1) First. After the cable lead to be added to the instrument has been cut to the required length and the conductor ends stripped and tinned, the total resistance of each individual conductor in the cut cable is measured and recorded.

(2) Second. Just prior to splicing the long cable to the short leads on the instrument, total resistances of the instrument coils and short leads are measured. These include -

(a) Expansion coil including white and green short leads.

(b) Contraction coil including black and green short leads.

(c) Expansion and contraction coils in series including black and white short leads. In addition, using the conductor common to both coils (green) as a leg of the Wheatstone bridge (Plate No. 2-2), the resistance of each coil is measured.

(d) Expansion coil only.

(e) Contraction coil only.

Also, the ratio of the resistance of the two coils is determined directly be means of the bridge.

(f) Resistance ratio at splice.

(3) Third. After the cable splice has been completed, a set of six resistance measurements similar to the series just described is made. These readings will include the effect of the full cable leads.

d. Data Sheet. Typical results of resistance calibration measurements are shown on Plate No. 2-3. These values provide the necessary information for correcting calibration factors, and, by properly combining the observed resistances, serve as a check on the operation of the instrument and in detection of improper splices and defective cable.

2-14. Correction Factors.

a. Calibration Factor Correction. The calibration factor furnished by the manufacturer (strain change per unit change in resistance ratio for strain meters, and similar changes for stress meters, joint meters, and hydrostatic pressure cells) is corrected by multiplying the given factor by the ratio of the measured series resistance of the two instrument coils and the entire cable leads to the measured series resistance of the same two coils and the short cable leads. This operation is shown on Plate No. 2-4. The correct calibration factor will always be greater than the initial factor, since the long cable leads introduce additional resistance into the circuit, thus demonstrating that the added cable leads reduce the sensitivity of the instrument. A correction factor ratio also may be calculated from the individual resistance readings made during the operational checking of the instrument, and it is even possible to arrive at a correction ratio after the instrument is embedded in the structure. These values are only approximate, and normally are used solely for checking the result from the more accurate method.

b. Temperature Factor Correction. The total resistance of strain units is frequently used to measure temperature at the instrument. With either 3-conductor or 4-conductor leads, compensating test set circuits may be arranged as shown on the wiring diagrams so as to eliminate the resistance of the added cable leads, provided the individual resistances of all conductors in the cable are precisely equal. Since this condition rarely exists with commercially available cable, the given meter resistance at the base temperature (usually 0°F) must be corrected to take into consideration the differences in resistance between the individual conductors of the added cable. The direct resistance measurements made previously of each added cable conductors are used for this purpose as follows:

(1) For 3-conductor cable - add, algebraically, the quantity $(2r_3 - r_1 - r_2)$, to the given meter resistance at the base temperature.

(2) For 4-conductor cable- add, algebraically, the quantity $(r_2 - r_1)$ to the given meter resistance at the base temperature.

Where: r_1 = resistance of the conductor lead (black) connected to the free end of the contraction coil

r_2 = resistance of the conductor lead (white) connected to the free end of the expansion coil

r_3 = resistance of the conductor lead (green) common to the contraction and expansion coils.

Normally no correction is applied to the given meter resistance change per unit of temperature furnished by the manufacturer. Temperature correction calculations are shown on Plate No. 2-4.

2-15. Resistance Thermometer Calibration. A similar type of temperature calibration correction is necessary for the resistance thermometers as for the strain units, but is accomplished by a more precise and accurate method. After the conductor splices have been made but prior to adding the insulation and completing the splice, the meter is immersed in a bucket of water at room temperature and allowed to remain long enough for the entire meter to reach a uniform temperature. Resistance reading (3-conductor compensating circuit) are then made in the usual manner at the splice and at the end of the added cable lead. The exact temperature of the water bath is not significant, so long as it is constant during the calibration readings of a thermometer. The corrected resistance calibration of the meter at the basic temperature (usually in ohms at 0°F) is obtained by adding, algebraically, the quantity (R'_y - R_v) to the basic resistance value furnished by the manufacturer,

where: R'_y = Resistance reading from test set at end of cable leads, ohms.

R_V = Resistance reading from test set at the splice, ohms.

Normally no correction is applied to the given meter resistance change per unit of temperature furnished by the manufacturer.

2-16. Final Calibration Adjustments.

a. Cable Length Adjustments. Further correction of instrument calibration factors is required whenever any appreciable length of conductor cable is added to or cut off from the initial length of added cable lead. Since all cable initially added to instruments has some allowance for contingencies which might be encountered during embedment, it is usually necessary to cut off some surplus cable when making permanent connections at the terminal. To adjust for the effect of possible changes in total conductor resistance and to detect changes in electrical circuits resulting from terminal connection operations, a series of resistance readings are made immediately prior to trimming off excess cable and again after the permanent terminal board or strip connection is completed.

b. Temperature Adjustments. Final adjustment of the temperature factor (ohms at 0°F) for resistance thermometers is obtained by measuring the 3-wire resistance of the instrument before and after trimming the cable lead. The previously corrected temperature factor (ohms per °F) is then adjusted by adding, algebraically, to the factor the measured instrument resistance after trimming minus the measured instrument resistance before trimming. No adjustment is made of the temperature calibration (°F per ohm change).

c. Strain Adjustments. For strain units the total resistance of the expansion and contraction coils in series including the attached conductors (black and white) is measured before and after trimming the cable. The final adjusted calibration factor (strain change, or similar stress, pressure or length change, per unit change in resistance ratio) is obtained by multiplying the previously corrected calibration factor by the ratio of the total resistance before trimming to the total resistance after trimming. No adjust is made of the temperature factor (ohms at 0°F) or of the temperature calibration (°F per ohm change) for strain-type instruments, except when 4-conductor cable is used. In that event the final adjustments are made in the same manner as is subsequently described for resistance thermometers.

2-17. Instrument Installation.

a. Personnel. The key man in all embedment operations is the instrumentation group leader. Aided by an assistant, he should be able to accomplish the placement of many of the thermometers, pore pressure cells, joint meters, and single strain meters, providing all the instruments are not to be embedded simultaneously within a lift. Where several stress meters, strain meters, or thermometer groups, all of which require considerable care in placement, are planned for a single concrete lift, the group leader will require the assistance of as many as three junior engineers or concrete technicians plus several unskilled laborers. The engineers do the actual placing of the instruments, directing the laborers in digging the required holes and cable trenches, and in backfilling over the meters. In extensive installations within one lift, fatigue and haste will usually cause a relaxation in the precision with which the last few strain or stress meters are placed, and ample personnel should be provided in order to avoid this situation.

b. Preliminary Preparations. As soon as the group leader responsible for the meter installation is designated, several weeks or months prior to the time the first instrument is to be installed, details of meter placement and alignment should be worked out in the project office. Locations of the instruments as indicated on the contract drawings should be checked for errors or impractical arrangements, and any necessary deviations presented to the District office for their concurrence. When "spiders" are to be used to support strain meters in their proper positions, they should be fabricated in the shop or purchased from a commercial source. If the strain meters are to be located and aligned by means of templates, these should be constructed. Block-out boxes, used to form temporary cavities or working spaces in which the groups of meters are to be placed, should be constructed of the proper size and shape. Pipe supports for strain meter boundary groups and for multiple thermometer assemblies should be fabricated. The sequence of instrument embedment should be established so that proper cable lengths can be ordered with the instrument to minimize the amount of splicing that is necessary and calibration operations for each meter can be scheduled in their proper order. In addition to providing for material and equipment requirements, personnel who are to do the actual embedment of stress meters and strain meters should become thoroughly familiar with the techniques involved. It is essential that trial runs of stress meter placement be made as part of the familiarization phase. The conditions of embedment are such that there will be no opportunity during meter embedment operations to consult written placement instructions, and a thorough knowledge of techniques is essential.

c. Final Preparations. Before concrete placement is started in the lift to contain the instruments, the group leader should tour the location, checking to see that cable conduits are available and clear and that recesses and terminal box block-outs are made. Arrangements should be made for such extra help as will be required during the installation. Survey points should be established and plainly marked so as to be visible and clear of concrete operations. Block-out boxes, templates, and instruments should be placed so as to be readily available.

2-18. Embedment Techniques. Installing strain meters is the most difficult and precise job involved in a special instrumentation program. Installing stress meters is somewhat less difficult, chiefly because fewer are installed at any one location, and placement often may be done following completion of a lift. Joint meters, resistance thermometers, and pore pressure cells require only moderate care in placement. Details of the established techniques for embedment of the Carlson transducer instruments described in this section (para 2-1 through 2-8) are given in Appendix C.

Section II: Terminal Facilities and Reading Equipment

2-19. Design of Terminal Recesses.

a. Location. Permanent facilities for making readings are provided in terminal recesses usually located in block-outs on walls of galleries nearest the instruments. It is customary to locate the recesses near a monolith joint in order that vertical runs of cable can be placed near bulkhead forms. The reading stations for all embedded instruments in a monolith should be located in that monolith if possible, in order to avoid running cable leads across contraction joints. sparate terminal recesses for cable leads from different types of instruments are not required. Where a gallery of similar semiprotected location is not available, a conveniently accessible exterior location may be selected, and the facilities secured against unauthorized tampering.

b. Size and Arrangement. Up to about 60 instruments may be served conveniently by a single terminal recess. More than this number create difficulty in bringing the cables into the recess and making connections to the panel board or terminal strip. The recess need not be lined, except that where only a small number of cables terminate at one station a commercial flush-type steel cabinet is acceptable. Outside reading stations require a weather-proof cabinet (Crouse-Hinds Co., 1347 Wolf St., Syracuse, NY 13201, traffic control box or similar). The bottom of the recess should be at a waist-level working height, and at least 1 ft of clear working space provided on the sides of the panel board or terminal strip to allow sorting and arranging of the cable leads. The door may be hinged on the bottom, and held in a horizontal position by chains when open to provide a convenient table space when making readings. If the doors are side-hinged, additional space is desirable within the cabinet for this purpose. A recess depth of at least 12 in, is necessary. Where auxiliary indicating or recording equipment is to be used, the recess should be enlarged sufficiently to accommodate these facilities.

c. Lighting. Normal gallery lighting is usually not adequate, and a supplementary fixture at the terminal reading station is necessary. A duplex convenience outlet, suitable for use in the reading station recess, is also recommended.

d. Moisture Prevention. To reduce corrosion at the cable terminals and panel board connections, usually a serious problem in dam galleries, an electrical strip heater should be installed within the terminal recess. A 500-watt heater is ample for a large recess. Where the reading station is small, a 100-watt heater may be used, or an ordinary 100-watt electric light bulb installed within the recess will serve the purpose.

e. Doors. Unlined recesses should be provided with angle-iron door frames and sheet steel doors with latch and lock. A closed recess aids in maintaining a more nearly moisture proof atmosphere around the panel board and automatic equipment, and provides security against tampering by curious workmen and other personnel. Doors for small enclosures should be hinged at the bottom, and snubber chains provided to hold the door in a horizontal position when open as a working space when making observations. Large enclosures usually have an ample interior working area.

2-20. Terminal Equipment.

a. General. To facilitate reading the embedded meters, the instrument leads terminate in the reading station at either a plug board or a terminal strip. Selector switches or automatic indicating or recording potentiometers, when used, are served from the terminal strip. Commercially available automatic equipment can be used only for direct resistance or voltage measurements. Some have microprocessors incorporated and are able to calculate resistance ratios from measured values and to perform data corrections.

b. Plug Boards. Plug boards are of 1/4-in. thick commercial bakelite, ebonite, hard rubber, or similar nonconductive material. Sheets are job-cut to size and drilled for insertion of lo-ampere telephone jacks or color-coded laboratory panel jacks. The board is held in place by brackets cinch-anchored to the recess walls or bolted to the metal cabinet, and the instrument identification numbers are stamped or painted on the board to identify the jack groups. A completed plug board is shown in Figure 2-11. In place of a separate jack for each conductor wire, reading operations can be expedited and positive electrical contacts more readily secured by installing ordinary 3- or 4-prong male electrical plugs in the board with the prongs protruding outward, and attaching the female socket to the short length of portable test cable lead.

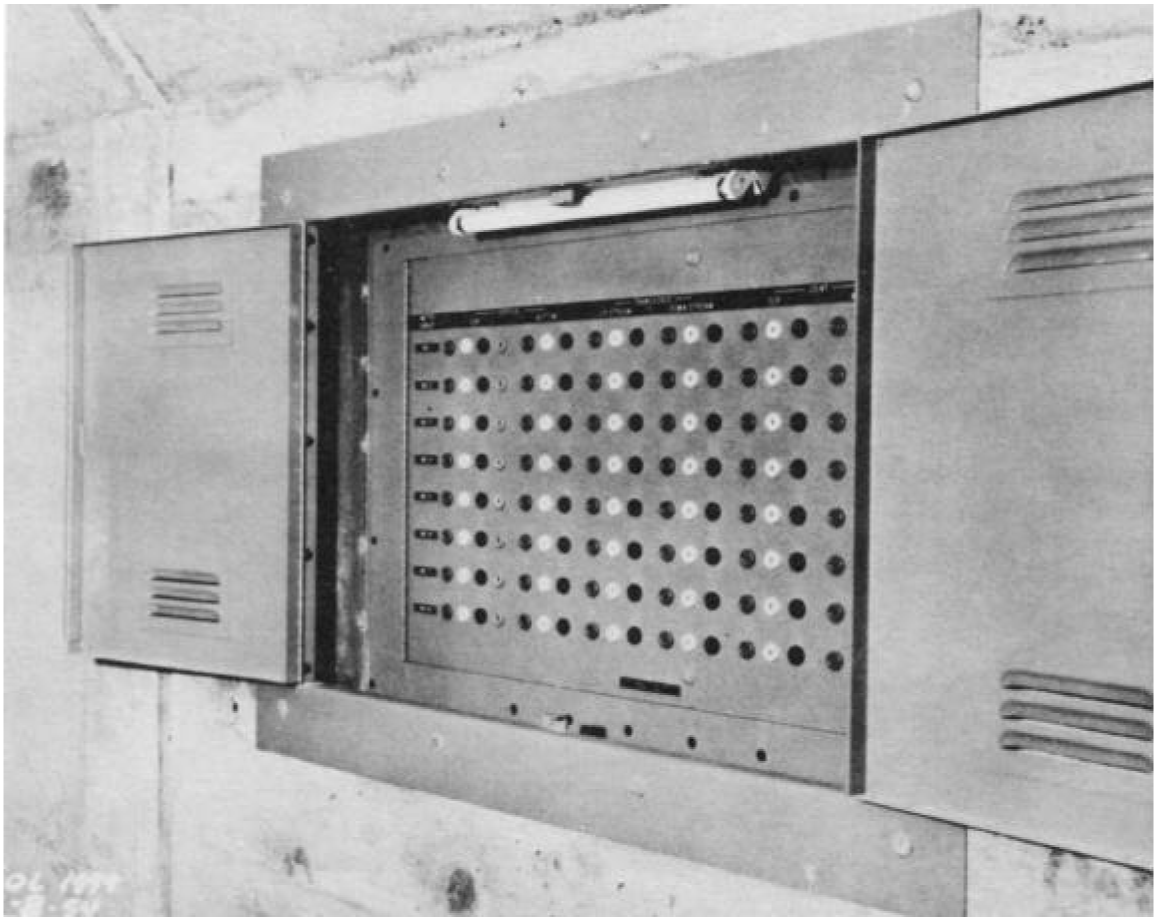


Figure 2-11. Plug Board in Folsom Dam. (Photo by CE-WES)

c. Terminal Strips. Commercially available terminal strips, Figure 2-12, cinch-anchored or bolted to the recess walls, serve as a termination point for the cable leads when supplementary indicating equipment is to be installed. Permanent soldered and moisture-proofed connections should be made on the embedded cable side of the strips, and reading instrument connections made with short lengths of insulated conductor from the other side of the strip.

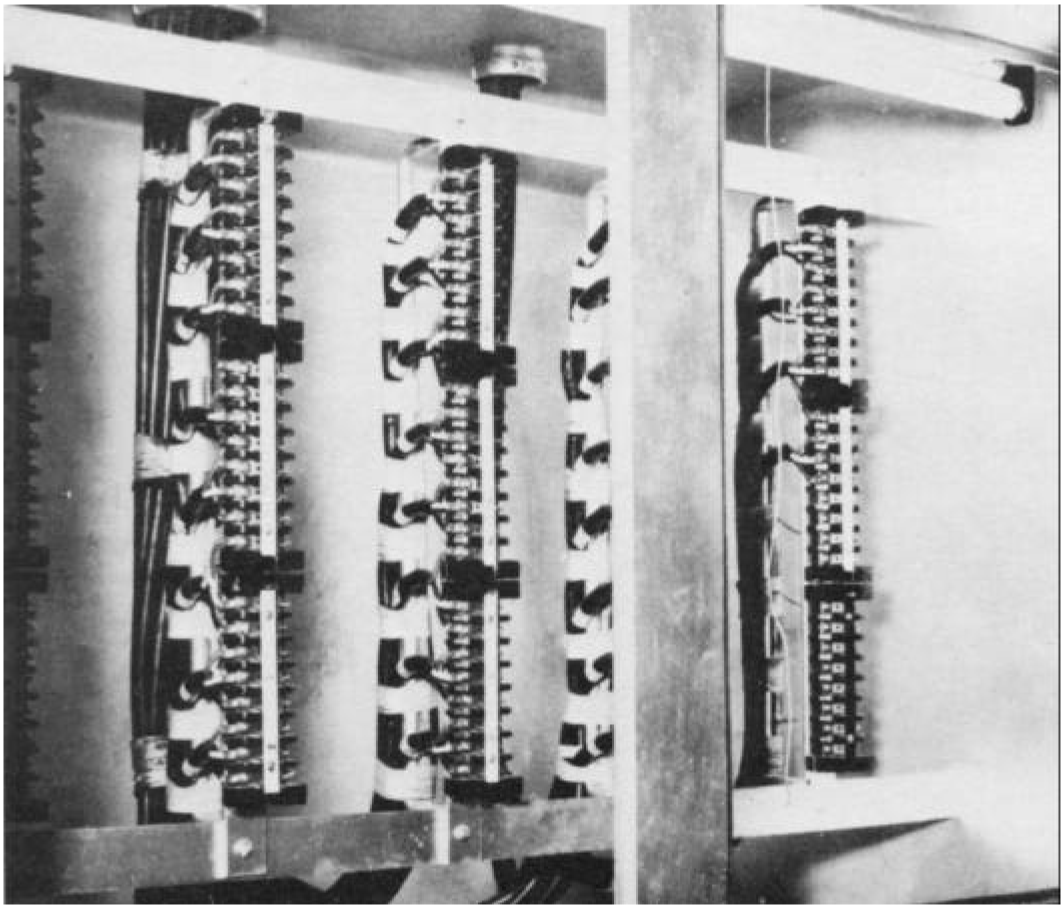


Figure 2-12. Terminal Strips in Reading Station Recess. (Photo by CE-WES)

d. Selector Switches. Equipment of this type, either commercially available or job-built, serves the same purpose as a plug board in that it facilitates making many successive connections during observation operations. Measurement of eletrical units is not accomplished by the switching device; a test set or potentiometer must be provided as with a plug board. Electrical contacts within the switch require periodic maintenance in order to avoid introducing extraneous resistances into the embedded instrument circuit.

e. Semiautomatic Indicating Equipment. When a large number of cable leads from resistance thermometers terminate at one reading station, the tedious job of manually balancing the Wheatstone Bridge of a portable test set for each thermometer during a set of readings may be eliminated by installing a multipoint indicating potentiometer in the terminal recess. One type of semiautomatic indicator, Electronik 15 Precision Indicator, manufactured by the Process Control Division of Honeywell, Inc., 1100 Virginia Dr., Ft. Washington, PA 19034, is available in capacities of 6-point multiples up to a maximum of 48 points. The instrument is basically a Wheatstone Bridge, automatically balanced by means of an electronic amplifier unit and a reversible two-phase motor which drives a slidewire contact to the balancing position. The various embedded resistance thermometers are cut into the circuit through a bank of push-button switches on the face of the instrument. Readings are indicated on a 9-in. diameter rotating disc scale which is driven to indicating position by the balancing motor. The instrument requires a 110-volt external power supply, 50 or 60 cycles, and thus cannot be placed in operation until power is available at the terminal reading station. It is usually necessary that the manufacturer make minor modifications to the standard instrument to adapt it for use with the Carlson resistance thermometer and the power supply available. In order to make certain that the equipment functions accurately and satisfactorily with the type of resistance thermometer with which it is to be used, temperatures indicated by the automatic instrument always must be checked, prior to installation of the equipment, against values as determined by a reliable manual test set. The instrument is not suitable for outdoor installation, nor can it be used for other than direct resistance (or temperature) measurements. A typical indicator installation is shown in Figure 2-13.

f. Automatic Recording Equipment. Continuous temperature readings over time periods of limited duration may be made with the Honeywell Electronik 15 Multi-Point Strip Chart Recorder, manufactured by the Process Control Division of Honeywell, Inc., 1110 Virginia Dr., Ft. Washington, PA 19034. These instruments are available in 2, 3, 4, 6, 8, 12, 16, or 24 point models, with many combinations of chart speeds, print wheel slide speeds, printing operation speeds, and continuous or intermittent printing sequences. The print wheel has different symbols or numbers on its circumference, and the wheel is rotated automatically one notch for successive printings. The recorder is a continuous-balance potentiometer which measures and records the magnitudes of a number of variables. It is supplied with the actuation, range, and number of recording points. Kits are available for changing the number of points, range of measurement, and type of potentiometer actuation, for example, change actuation from millivolt to thermocouple actuation. As with the semiautomatic indicator, its operation with the resistance thermometers to be used must be checked prior to installation. Use of the instrument is subject to the same limitations as the Honeywell Precision Indicator in regard to voltage and frequency of the external power supply, indoor use, and direct resistance measurements. A Honeywell Electronic 15 Multi-Point Strip Chart Recorer is shown in Figure 2-14.

g. Multiple Position Terminal Switches. For convenient readout of many gages without the need to change the leads of the reading equipment from cable to cable, multiple position terminal switches are available. Leeds and Northrup Co., Dept. MD337, North Wales, PA 19454, manufactures a 3-or 4-pole, 12-position, rotary selector switch that will accommodate up to twelve gages. Three switches per panel can be installed on each board as is shown in the surface mounted readout box shown in Figure 2-15.

2-21. Installing Cable Leads.

a. Cable Orientation. In general, instrument cable leads are run horizontally within the concrete lift containing the embedded instruments to the terminal recess or to a point directly above or below the terminal recess location. Where a group of several cables are to be run horizontally in a lift, they may be taped together at intervals and laid on the top of the next to last layer of concrete in the lift, covered with pads of fresh concrete at several points along their length, and placement of the final concrete lift layer allowed to proceed in the normal manner. Single or pairs of cable leads may be "walked into" the concrete, aided by inserting the vibrator into the concrete layer at intervals along the cable run. With this method care must be exercised to obtain adequate and complete embedment of the cable in order to avoid damage during subsequent lift joint clean-up operations.

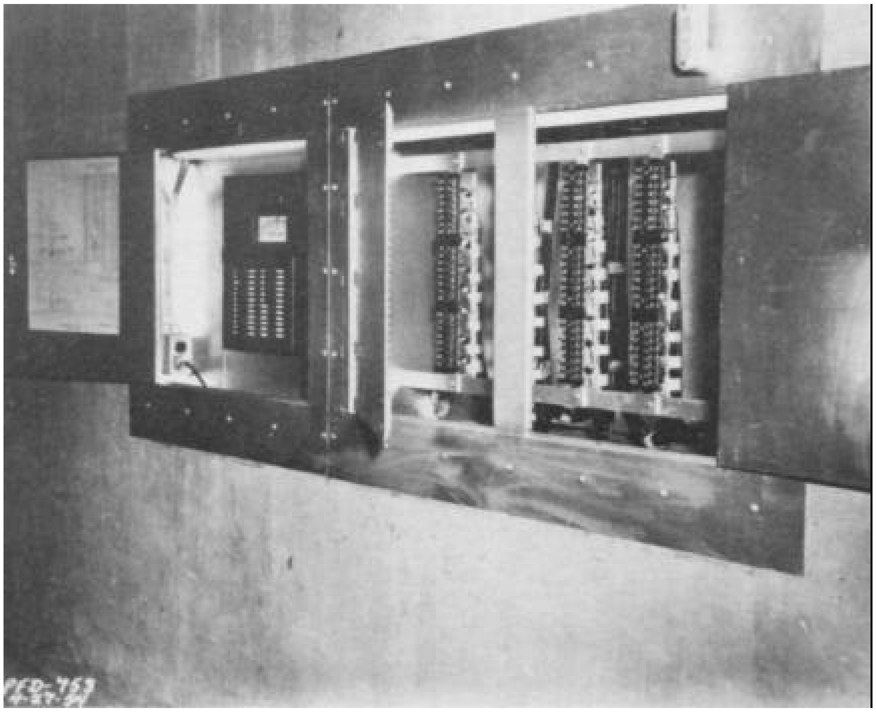


Figure 2-13. Indicating Potentiometer in Reading Station.
(Photo by CE-WES)

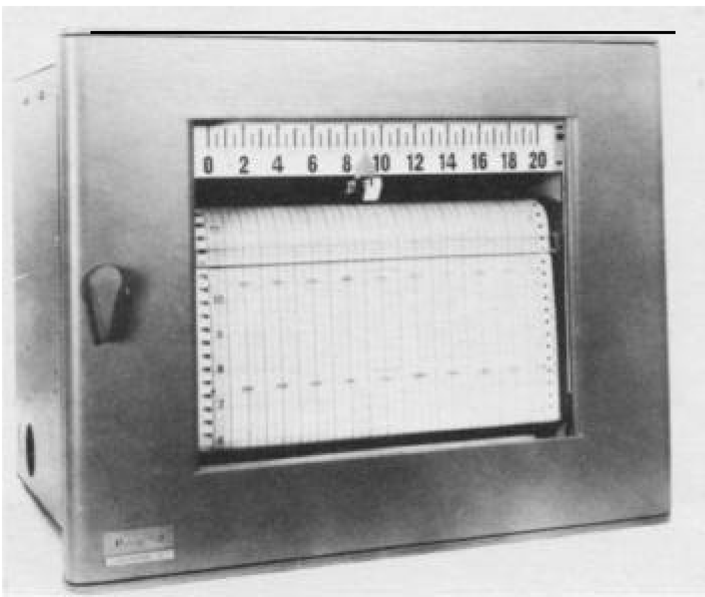


Figure 2-14. Recording Potentiometer (Courtesy of Honeywell, Inc.).

b. Instruments Above Terminal Reading Station. Cable leads are run downward in conduit from the lift containing the instruments to the terminal recess, with separate conduits serving each individual lift. The cable conduit should enter the terminal recess from the bottom of the recess to eliminate water from condensation or drainage flowing over the panel board. Figure 2-15 shows a typical surface mounted reading station with the conduit entering from below. Steel or iron pipe is commonly used for conduit, particularly for the longer vertical runs, but conduit of any material which will not collapse in fresh concrete is frequently satisfactory. Every effort should be made to avoid having a splice in the section of cable which is to be threaded through a conduit.

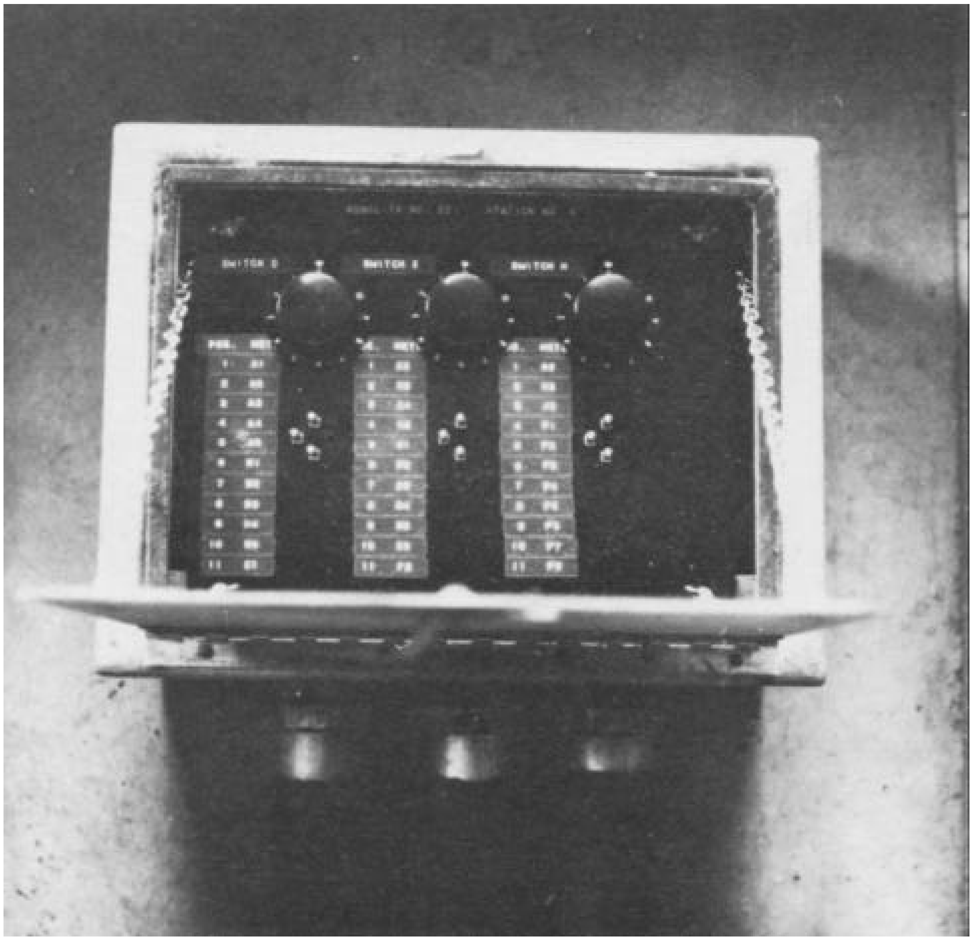


Figure 2-15. Surface-Mounted Terminal Station with Multiple Position Terminal Switches Showing Conduit Fed in from Bottom. (Photo by CE-WES)

c. Instruments Below Terminal Reading Station. Cable leads are run upward without conduit from the lift containing the instruments to the terminal recess. Vertical risers of pipe or reinforcing bars embedded in the concrete of each successive lift are helpful in providing a support for the cables. The cables are simply taped to the riser pipe at short intervals before placing each lift, and the remainder of the cable coiled and hung clear of the fresh concrete.

d. Size of Conduit. Size of conduit required is determined graphically by drawing contiguous circles of diameters equal to that of the cable, in a general circular group, providing for 1-1/2 times the number of cables to be accommodated where the conduit run is short, and up to twice the number of cables where the run is long or where there are bends. Circumscribe the group of circles with a larger circle to determine the inside diameter of the conduit. This is illustrated in Figure 2-16 where a conduit is being sized to hold ten 1/4-in. diameter cables.

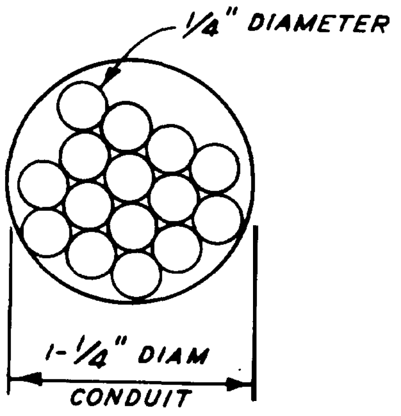


Figure 2-16. Method of Sizing Conduit to Hold Ten 1/4-in. Cables. (Prepared by WES)

e. Installation of Cables. Cables should be separated and threaded individually into conduit, in order that each cable will be required to support only its own weight. At conduit entrances burlap or similar padding should be provided around each cable and in the interstices between the cables to prevent sharp bends and to exclude concrete and grout from the conduit. Any cable purchased should have filler material for good round firm cable, and the conductor insulation solid color-coded. In lifts where many cables are to be brought together and run downward in conduit, the operation may be accomplished in two steps. First, a wood box or frame is placed around the upper end of the conduit to form a blockout about 18 in. in the concrete lift surface. The cables are embedded in the concrete as usual, brought into the blockout and hung clear of the fresh concrete. Second, on the next day, or when the concrete has hardened sufficiently to bear traffic, the cables are taken down, separated, and threaded through the conduit. This procedure allows the lift to be topped out without interference or delay, facilitates the threading of the cable through the conduit by keeping it clean, and avoids the haste which usually is associated with the final threading operation.

f. Cable Runs Across Joints. When it is necessary for the cable leads to cross expansion or contraction joints in the structure, a "slack cable" recess must be provided at the crossing point. This may consist of a wooden box blockout, as shown in Figure 2-17, forming a recess into which the newly placed cable is run. During placement of concrete in the adjacent monolith or column, a 1-ft loop of slack cable is left in the unfilled blockout, and the remaining length of cable lead extended and embedded in the new concrete in the usual manner.

2-22. Installing Terminal Equipment.

a. Cable Preparation. After all cable leads have been brought into a terminal recess, the surplus cable is cut off and the ends of the individual conductors prepared for permanent connection to the panel board or terminal strip. The metal identification tags attached near the original cable ends should be removed and refastened to the cable above the proposed cutoff point.

b. Eletrical Connections. Soldered cable connections at the panel board or terminal strip are required. After connections have been completed and are dry, two coats of a commercial electrical insulating varnish should be sprayed over the exposed conductors and connections to afford protection against moisture.

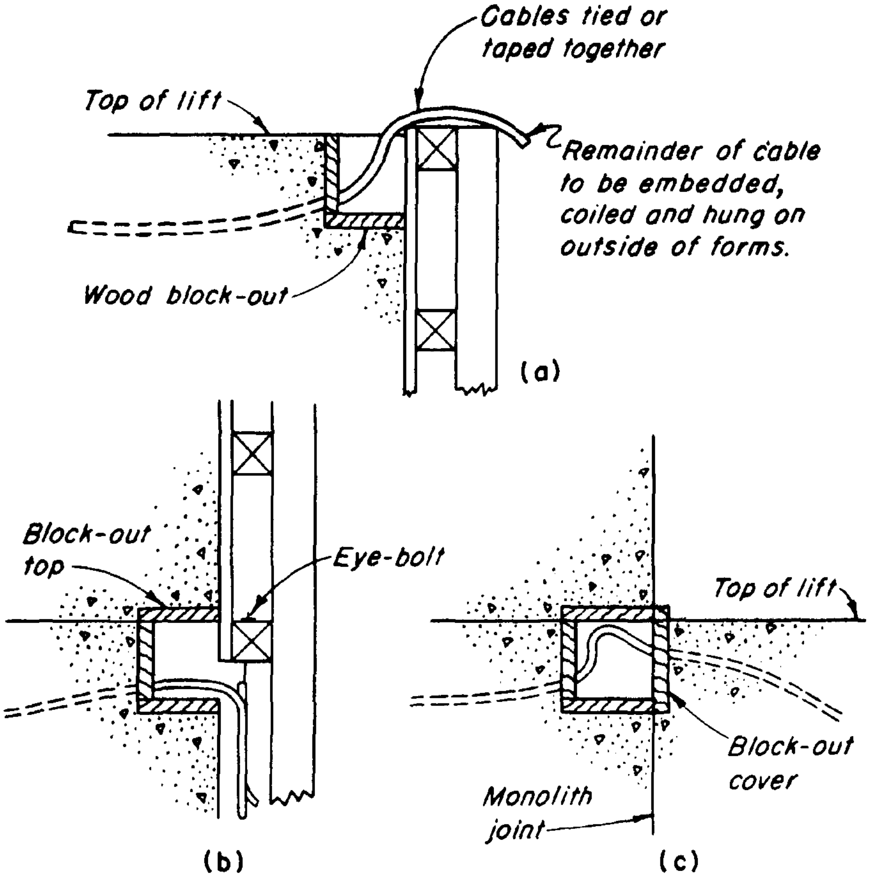


Figure 2-17. Slack Cable Recess. (Prepared by WES)

c. Instrument Check Readings. In order to make the final calibration corrections for each instrument and to check the quality of the connections, manual test set readings are made of each instrument immediately prior to trimming the surplus cable, after trimming the cable, and from the panel board or terminal strip after connections have been made. These readings should be recorded on the field data sheets and final calibration constant corrections made, if required.

d. Read Out Boxes. All read out boxes should be the same dimensions, a convenient size being 18- by 13- by 8-in. The box should be constructed of welded steel with a hinged door that is chained such that when it is let down it forms a table for the read-out bridge or for recording data. These boxes are used either exposed, wall-mounted, as in Figure 2-15, or installed in blockouts on steel face plates.

2-23. Reading Equipment.

a. Carlson Test Set. The Carlson test set shown in Figure 2-18 is basically a portable Wheatstone Bridge, consisting of a galvanometer, two known equal resistances, a variable resistance, and suitable binding posts for use with 2-, 3-, or 4-conductor cable. The variable resistance is adjusted by means of four decade dials, permitting resistance measurements from 0.01 to 109.00 ohms and resistance ratio measurements from 0.0001 to 1.0999 to be made. Direct readings of 2-wire resistance, 3-wire resistance, 3-wire resistance ratio, or 4-wire resistance and resistance ratio may be made with the same test set by proper binding post connections and galvanometer switches. Thus the Carlson test set is suitable for use with all the Carlson-type instruments. Schematic wiring diagram and operating instructions are shown on the interior of the test set cover. Similar wiring diagrams are given on Plates No. 2-1 and 2-2.

b. Biddle Test Set. The Biddle Test Set, No. 72-4010, is a special Bridge that is also designed for use with all Carlson instruments and can be obtained from James Biddle Co., Township Line and Jolly Roads, Plymouth Meeting, PA 19462.

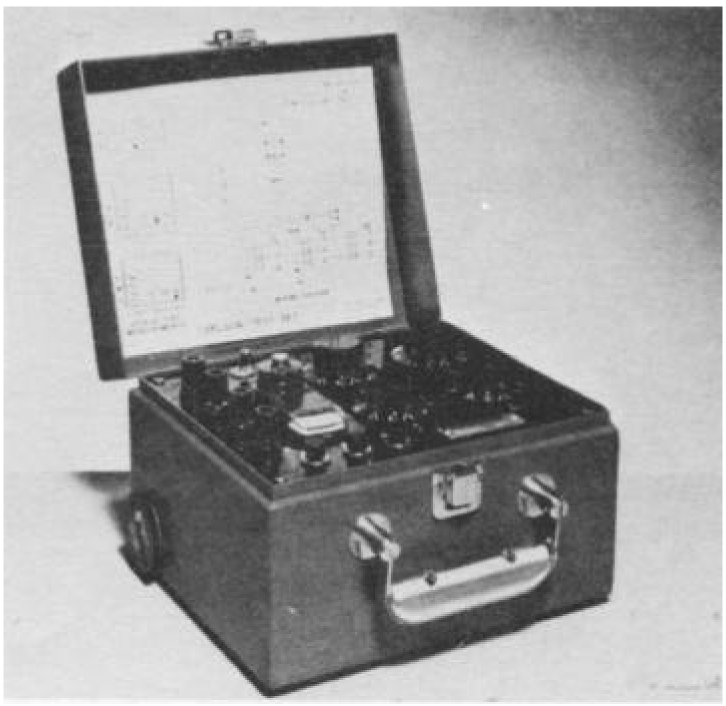


Figure 2-18. Carlson Test Set. (Photo by WES)

c. Maintenance. The current activating the galvanometer is supplied by ordinary flashlight batteries contained in the test set box, and the batteries should be replaced at intervals of not more than six months or whenever the galvanometer needle deflections become weak or sluggish. Holding the galvanometer switch button down continuously while balancing the bridge causes an excessive drain on the batteries as well as raising the temperature of the embedded instrument resistance coils, and should be avoided. At least once each year or whenever there is reason to suspect malfunctioning of the test set, the test set should be partially dismantled, accumulated dust and dirt removed from the decade dial spindles, and the decade resistance buttons and contact arms cleaned and polished. A light film of petroleum jelly wiped onto the contacts will aid in maintaining a satisfactory contact surface. For more extensive repairs of recalibration it is recommended the test set be returned to the supplier.

d. Recorders. For a continuous monitoring of the Carlson instruments the use of multi-point strip chart recorders will monitor up to 24 instruments. Para 2-20.f. gives detailed information about these recorders.

Section III: Data Collection and Reduction

2-24. Collection of Data.

a. Data Sheets.

(1) Field Reading Sheets. Resistance and resistance ratio readings from all Carlson-type instruments may be recorded on field reading sheets (prepared in advance) similar to Plate No. 2-5. The established instrument numbers and symbols are printed in the first column, the previous resistance and ratio readings entered in the second and third columns, and the remaining columns provide space for recording the current measurements. By placing duplicate sheets in a clip board, suitably offset and with a sheet of carbon paper between, the readings recorded during one series of observations are printed on the second sheet as "previous readings" for the next series of observations. The value of having the previous readings readily available lies in the opportunity thus afforded the observed for quickly checking and comparing the current measurements, and unusual, excessive, or erroneous readings may be immediately detected. A second or check reading may then be made.

(2) Data Record Sheets. Individual data record forms should be provided for each separate embedded instrument. These sheets provide a place for recording the location of the instrument, original and corrected calibration constants, lead resistances, temperature correction equations, zero resistance and ratio readings, and any other pertinent instrument characteristic. Reduction and conversion of the indicated readings to the desired units of stress, strain, temperature, joint movement, or pore pressure is made on this data sheet. Sample sheets suitable for the various types of Carlson instruments are given as plates No, 2-6 to 2-10 inclusive.

b. Protection of Accumulated Data.

(1) Transfer of Data. The measurements recorded on the field reading sheets should be transferred to the individual data record forms with the least practicable delay after each set of readings are made. Transcribing of these data should be carefully done, and checked at least once in order to reduce the possibility of errors. Utilizing data record forms in this manner eliminates the necessity for exposing the only copies of accumulated readings for each instrument to the possibilities of loss or damage while making observations under job conditions. The practice of using field books for recording the readings is not recommended, since column headings and instrument numbers must be inserted by the observer, and considerable irreplaceable data are taken onto the job for each set of readings (frequently before the results have been transferred to data record forms).

(2) Filing Field Reading Sheets. After the readings have been transferred to data record forms, field reading sheets should be retained in the field office until analysis of the collected data has progressed to a point where any questionable readings have been detected and checked against the original recorded values.

(3) Filing Data Record Sheets. As each individual data sheet is completed it should be forwarded to the office where the analysis is to be accomplished. This practice will provide additional protection against loss or destruction of accumulated data, since the original field reading sheets will be retained in the field office.

2-25. Reading Schedules.

a. General. Initial readings must be made within three hours after embedment of the instruments and continued at frequent intervals during early ages in order to measure the rapid volume, stress, and temperature changes resulting from hydration of the cement. After maximum temperatures have been attained the observation frequency may be reduced, since volume, stress, and temperature change more slowly during the cooling-off period. A further reduction in reading frequency is permissible after much of the heat of hydration has been dissipated and the structure is responding to normal climatic and load cycles. In the interest of simplicity in establishing a reading program it is generally advisable to refer progressive decreases (or increases) in observation frequencies to "days after embedment" for each instrument rather than stages of temperature or heat loss. The recommended duration of the various reading frequencies are intended to represent minimum requirements and to serve as a guide in establishing a reading program. In practice, changes in observation frequencies for some instruments are deferred until such time as the change may be made simultaneously for a large number of instruments.

b. Strain Meters. A normal program consists of an initial reading made between 1 to 3 hours after embedment, readings twice daily for 3 days, once daily for the next 12 days, twice weekly for the next 4 weeks, weekly during the remainder of the construction period, and twice each month thereafter.

c. Boundary Strain Meters. The observation program for boundary meter groups would be similar to the normal program, except that the twice daily readings should be continued for the first 15 days after embedment.

d. Joint Meters. Joint movements usually occur slowly and over extended periods of time. A normal program would consist of an initial reading between 1 and 3 hours after the meter is covered, then weekly during the remainder of the construction period, and twice each month thereafter.

e. Stress Meters. The normal observation program for stress meters may be similar to that described for strain meters.

f. Pore Pressure Cells. Hydrostatic pore pressures within concrete develop slowly, and occur only when a hydraulic head is sustained for an extended period against the concrete surface. The normal pore pressure cell reading program includes an initial reading at 1 to 3 hours after embedment, subsequent readings at weekly intervals after the reservoir reaches the level of the instruments until the operating pool elevation has been attained, and twice monthly thereafter.

g. Thermometers.

(1) General. The normal observation program as described for strain meters should be followed for all embedded thermometers except those specifically covered hereinafter.

(2) Thermometers in Foundation Rock. An initial reading should be made as soon as the instruments are installed, and continued at daily intervals until the first concrete lift is placed above their location. Subsequent observations should conform to a normal program generally applicable to thermometers.

(3) Thermometers Adjacent to Horizontal Lift Surfaces. The primary purpose of thermometers located at various depths within a concrete lift is to establish temperature gradients and heat losses during the exposure interval. Thermometers located in lifts placed under nominally continuing concrete operations (exposure interval of only several days between successive lifts) should begin at 1 to 3 hours after placement, and continue at twice daily intervals (or a continuous record secured from strip chart recorders) until no significant temperature gradient exists within a single thermometer group. At that time observations may be terminated on all instruments except one, and this selected typical thermometer incorporated in the long-time temperature observation program for the structure.

(4) Thermometers in a Top Lift. Where a vertical line of thermometers is located in a top lift which is to be exposed for an extended period of time (such as during the suspension of construction over the winter season or during concrete operations in other stages) the observation program should consist of the usual early initial reading, twice daily readings for 10 days, and daily readings over the remainder of the exposure period. After the covering lift is placed, the daily readings should be continued until such time as a reasonably uniform vertical temperature gradient exist through the previously exposed lift. Observations may then be terminated on all instruments except one in the group.

(5) Thermometers Adjacent to Bulkhead Faces. An adequate reading program will usually consist of the intial observation at 1 to 3 hours after embedment, twice daily readings for a period of 15 days, and at daily intervals thereafter until concrete in the adjacent block has reached an elevation above the thermometer group level and no significant temperature gradient exists within the group. One instrument may then be selected, if desired, to be incorporated in the thermometer pattern for the monolith and observations of the remainder of the meters terminated.

(6) Thermometers Adjacent to Exterior Faces. The normal reading program followed for interior thermometers will be satisfactory, with the exception that the twice-daily observations be continued for the first 15 days after embedment.

h. Special Stress, Strain, and Temperature Readings. In order to determine the effect of daily cyclic or other comparatively sudden climatic changes, and extremes of ambient air temperature on the development of stress, strain, or temperature gradients within a structure, several series of continuous readings (of up to two days duration) should be made on instruments located near exposed surfaces. Each set will consist of test set readings (or a strip chart temperature record if automatic equipment is used with thermometers) at 3 or 4 hours intervals over a 48-hour period. These observation series are usually made in pairs, during the spring and the autumn seasons to define the maximum range in daily temperature cycles and during the winter and summer seasons to coincide with the extremes of air temperatures. Similar types of observations are also made on embedded instruments adjacent to insulated surfaces to measure the effect of such insulation.

i. Extended Reading Schedules. Reading schedules can be extended to once monthly or even once quarterly after a sufficient amount of time has elapsed to verify that the change in reading will only be small between the specified time interval. However, if extended reading schedules are utilized and any abnormal occurrence should happen, readings should be made immediately and the reading schedule should return to that used for a new gage.

2-26. Field Reduction of Data.

a. Field Office Preparation. The term "reduction of data" refers to the arithmetical operations necessary to convert individual instrument readings into significant units of stress, strain, temperature, length, or pressure. It is desirable that these operations be performed in the field office in order that possible reading errors may be detected as soon as possible, explanations for apparently unusual results more readily and promptly secured, and preliminary results made available for use by project engineers at an early date. The practice of deferring office calculations for several months until construction work slackens or having the data reduction work accomplished at other than the project office, should be avoided.

b. Required Calculations. Reduction of data calculations required for Carlson-type instruments includes one or more of the following general operations: calculations of meter temperature, application of the calibration constant to the measured resistance ratio, and correcting the indicated results for the effects of temperature changes in the concrete and in the meter. Step-by-step explanation of these procedures is given on plates No. 2-6 through 2-10 for the several Carlson instruments. Specific examples of the transfer of raw data to finished numbers of strain, stress, pressure, and movement are given in Plates 2-11 through 2-14.

c. Personnel. On large and important instrumentation installations a field group should be established, under the project engineer, to carry out the functions of preparation, calibration, and installation of the instruments, making subsequent observations, reduction of the collected data, and the collection of additional related data as required. The group should be headed by an engineer with a civil, structural, or electrical background, whose primary duty will be the prosecution of the instrumentation program. A short period of supplementary training for this instrumentation group leader in the District Office Engineering Division, covering the purposes of the proposed instrumentation program, operational principles of the instruments, embedment practices, and observation program is recommended in order to assure a successful structural behavior investigation study. The remainder of the group will consist of personnel whose primary duties are in connection with inspection or laboratory activites, but may be made available to the extent required for the preparation and embedment of the meters and for making subsequent observations.

(1) Extensive Installations. A field group for an extensive instrumentation installation will likely require one or two full-time group leaders, a full-time electrician, and three or more junior engineers or concrete technicians for part of the time. Supplementary unskilled labor will be needed during embedment operations. Preparation of the instruments, cable splicing, and installation of indicating and recording equipment is done by the electrician and the engineers make the calibration checks on the instruments and do the actual placement.

(2) Small Installations. Where the number of instruments is comparatively small, and where embedment procedures are simple, one engineer or capable technician will be able to carry out alone all the work incident to preparation, installation, and reading of the meters.

d. Office and Working Space. To support a major instrumentation program (800 to 1000 or more instruments), about 300 sq ft of laboratory and shop working space should be provided, consisting of work benches, storage cabinets, shop facilities, and office space solely for use in connection with the instrumentation program. For small installations, the project laboratory facilities will normally be adequate.

Section IV: Other Stress-Strain Type Transducers

2-27. General. The gages described in the following paragraphs are various stress-strain type instruments that have been used in recent years to perform specialized tasks. The majority of the gages are electro-mechanical; however, some are purely mechanical type gages. Some of the gages are more sensitive than previously described stress-strain gages and may not be suitable for long-term exposure type of monitoring tasks.

2-28. Strain Measuring Instruments.

a. Types. Two types of gages are generally used for measuring strains: surface gages and internal or embedded gages. These types can be further divided into short- and long-term gages, depending on the duration of measurements. Usually short-term strains are best measured by electrical type gages, while some long-term strains (e.g., creep and shrinkage) can be conveniently measured using detachable mechanical gages. Some of the gages used for measuring strain in structures are described below.

b. Whittemore Mechanical Strain Gage.

(1) Description. This is a universally accepted gage for measuring long-time static strains on structures. Strain is derived essentially from measuring changes in distances between attached reference points on the structure. Reference points are located on the structure by bonding contact seats to the surface of, or by drilling holes in the structure wall and embedding inserts for supporting contact seats. The Whittemore gage shown in Figure 2-19 has conical points which are seated in small holes in the reference points when strain measurements are made. The dial attached to the gage indicates the positions of the two reference points from which the strain is obtained before and after the stressed condition. The gage has a gage length of 10 in. and readings to one ten-thousandth of an inch (0.0001 in.) can be made. This gage and its accessories are available from Soiltest, 2205 Lee Street, Evanston, Illinois 60602.

(2) Calibration and Gage Accuracy. An invar master bar, shown in Figure 2-20, with stainless steel inserts is used for standard measurements, The gage kit includes: brass inserts; contact seats; invar master bar; and strain gage punch bar for accurately locating inserts. Repeatability of this gage is generally found satisfactory if the same operator always reads the gage. With care taken, the operator can repeat a measurement of 0.0001 in. The gage readings are linear over the 0.200-in. range. The indicator is accurate to 0.0005 in.

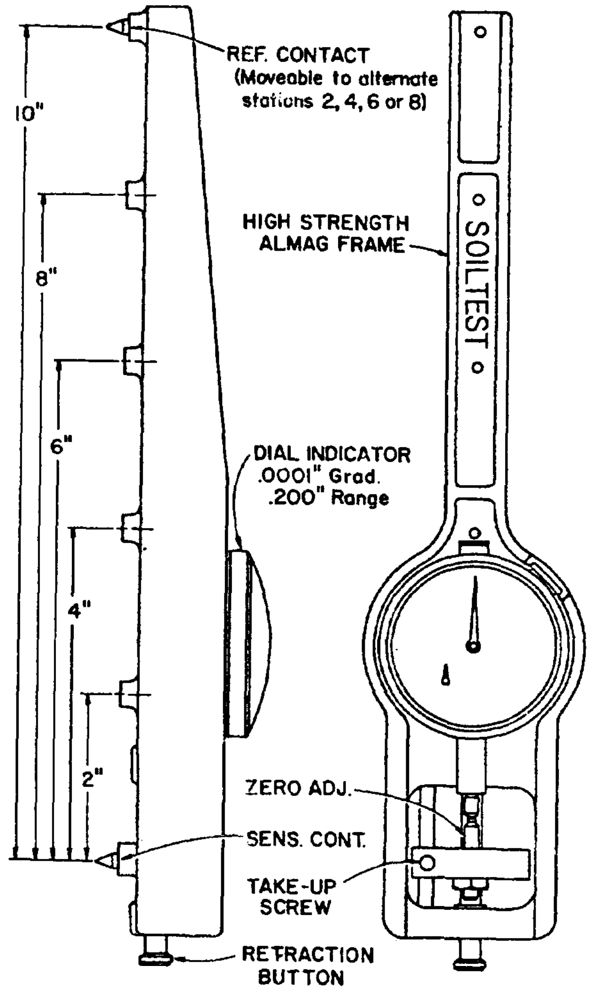


Figure 2-19. Whittemore Type Mechanical Strain Gage (Courtesy of Soiltest, Inc.).

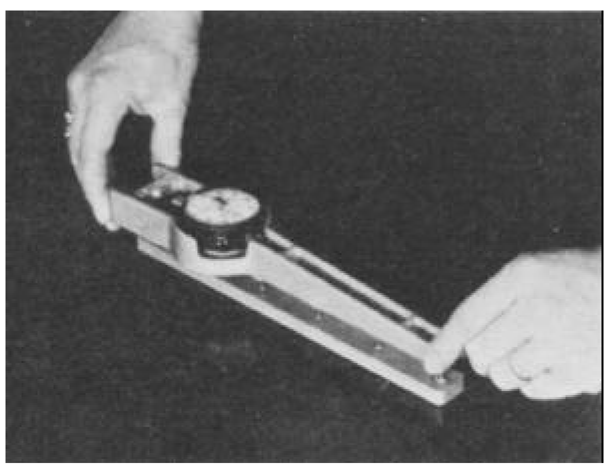


Figure 2-20. Whittemore Type Strain Gage in Position on Invar Master Bar (Courtesy of Soiltest, Inc.).

c. Mechanical Scratch Gage.

(1) Description. The temperature compensated, self-contained scatch gage measures strains or tiny movements that occur in most structures. In this scratch gage, a tiny arm carrying a recording scriber serves as a gage point. The scriber sharply scratches the amount and direction of deformation on a round, polished-brass recording head or "target" which is the opposite gage point. The gage is attached to structures with clamps, drive screws or adhesives. Recordings can be made over long periods of time, yet it easily records rapid events. The gage operates accurately in the open within a temperature range of -67°F to 1000°F. It also works well under water and is not affected by pressure. It is very durable and can be used over and over. The gage accuracy is determined by the reading equipment. The strain can be determined from the scribed disk using a calibrated eyepiece or microscope.

(2) Principle of Operation. As shown in Figure 2-21, the circular target is held in place by two tiny rollers and two stainless steel brushes. The long driver brush is made up of small wires. One end of the long brush is fixed to the small base plate and the other end terminates in a peripheral groove of the target. It is guided and supported between these two points through a small bent tube. A short wire brush engages the target groove adjacent to the long driver brush and is fixed on the other end to the large base plate. The short brush holds the circular target firmly against the rollers to eliminate false readings due to play. When tensile strain occurs, the two base plates move apart causing the scriber to scratch the disk (Figure 2-22), recording the total strain. When the strain is relieved, the target automatically rotates, allowing separation of each tensile strain. When compressional strain occurs, the two base plates move together, causing the scriber to scratch the disk in the opposite direction. The longer driver wires engage the surface of the target groove, causing the target to rotate. The shorter brush prevents reverse or clockwise rotation.

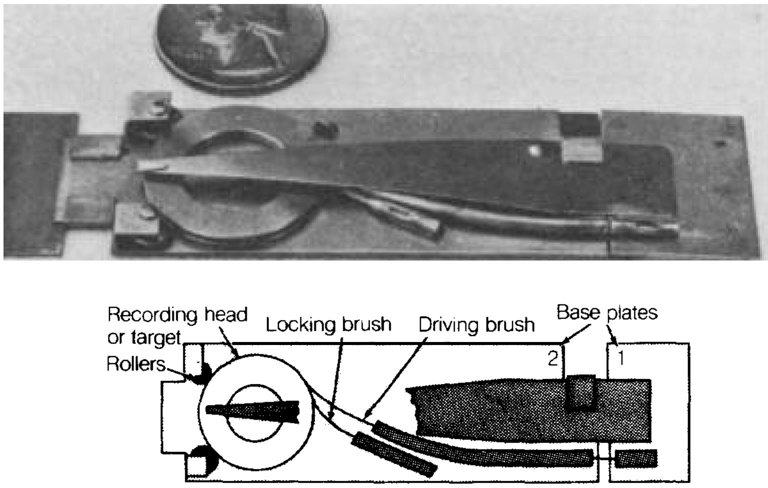


Figure 2-21. Mechanical Scratch Gage (Courtesy of Prewitt Associates).

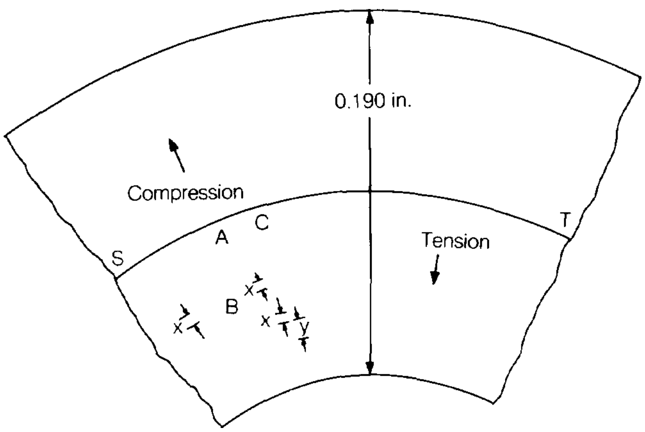
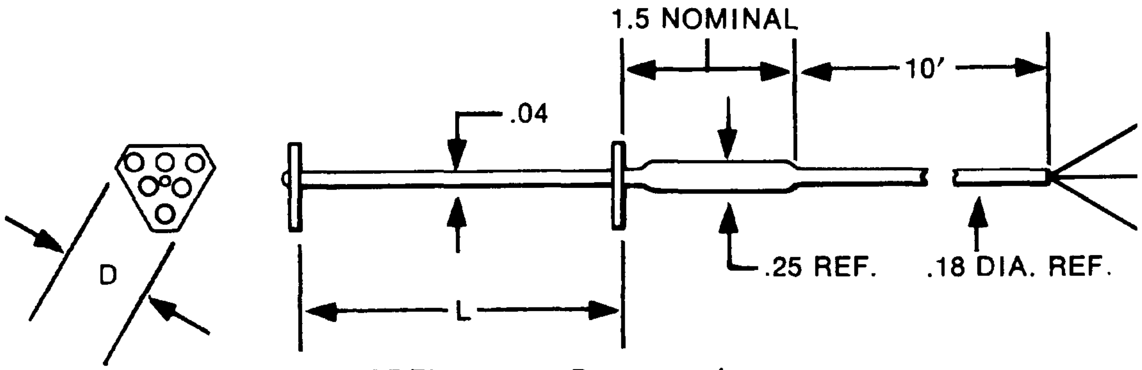


Figure 2-22. Typical Scratch Representation (Courtesy of Prewitt Associates).

d. Embedable Strain Gages.

(1) Principle of Operation. Recent developments in the technology of strain gages have produced lightweight embedment type strain gages that are suitable in mass concrete. The transducers operate on the principle that the resistance of a wire varies directly with strain in tension or compression. Figure 2-23 shows an embedable strain gage manufactured by Ailtech, a Cutler Hammer Company, 19535 E. Walnut Drive, City of Industry, California 91748. The Ailtech gage consists of a short length of nickel-chromium, platinum-tungsten, or similar alloy wire which has been electro-formed or etched so that a sensitive element is formed. The wire is insulated by highly compacted magnesium oxide powder and encased in a small diameter tube made of stainless steel, aluminum, titanium, Inconel or gold alloy. The gage has two end flanges which serve to anchor it in the concrete at the location where strain is to be read. Embedment techniques should be similar to those used to embed the Carlson instruments outlined in Appendix C.

(2) Gage Properties. The temperature compensated embedable strain gage is suitable for measurements of tensile or compressive strain levels to 6000 microinches per inch over extreme temperature ranges. It is completely hermetically sealed and waterproofed with mechanical protection from the gage to the flexible waterproof cable. The gages can be obtained with both quarter and half bridge, 60, 120, or 360 ohm active units. Standard bridge completion network and power supply can be used with these gages.



MODEL	D	L
CG2-129	.68	2.00 ±.02
CG4-129	.87	4.00 ±.03
CG6-129	.87	6.00 ±.03

Figure 2-23. Ailtech Embedable Strain Gages (Courtesy of Ailtech).

e. Vibrating Wire Strain Gage.

(1) Principle of Operation. A vibrating wire strain gage consists of a pretensioned fine steel wire clamped between two end flanges and enclosed in a stainless steel or acrylic tube. The end flanges can be welded or bolted to the surface of a structure or can be cast in place in concrete. Forces acting on the structure produce strains which introduce relative movements between the end flanges and thus a change of tension in the steel wire. A dual purpose electromagnetic coil is mounted in the gage housing, adjacent to the wire, and is electrically coupled to the measuring equipment by a flexible cable. A current pulse, generated by the measuring equipment, energizes the coil, thus plucking the wire and causing it to vibrate at a natural frequency determined by the tension in the wire. The vibrating wire, in turn, induces an ac voltage in the coil with a frequency corresponding to that of the vibrating wire. The frequency of the coil output voltage is sensed by the measuring equipment. The fundamental natural frequency of a stretched wire is given by $f = \frac{1}{2\ell}\sqrt{\frac{T}{M}}$ (where ℓ is the length of the wire between the clamps; T, its tension; and M, its mass per unit length).

(2) Advantages. The main advantages of the vibrating wire meter are: good long-term stability; high sensitivity; unaffected by cable lengths; and relatively insensitive to moisture and resulting electrical ground leakage. Figure 2-24 is a picture of a typical vibrating wire gage.

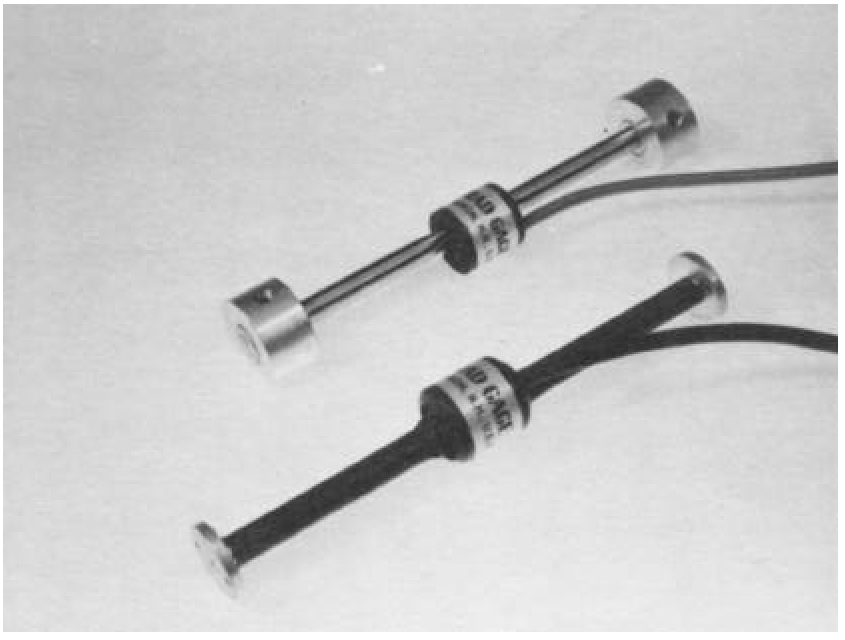


Figure 2-24. Vibrating Wire Strain Gages (Courtesy of Irad Gage, Inc.).

(3) Reading Equipment. Solid state portable digital readout instruments are available for use with the vibrating wire gages. Irad Gage, 14 Parkhurst St., Lebanon, New Hampshire 03766, manufactures both vibrating wire gages and readout devices, as do other geotechnical instrumentation manufacturers. The Irad readout box operates by initially generating a voltage pulse containing a spectrum of frequencies spanning the natural frequency range of the wire. When the signal reaches the coil/magnet assembly mounted inside the gage and when one of the input frequencies coincides with the natural frequency of the wire, the wire vibrates and continues to vibrate after the input signal has ceased. A voltage is then generated in the coil at a frequency corresponding to that of the wire as it vibrates in the field of the coil/magnet assembly. This constant frequency signal generated by the gage is timed by a precise quartz clock in the readout meter and the time displayed digitally.

(4) Operation. To obtain useful readings, the operator: connects the gage; sets a switch to one of two positions corresponding to gage type; and depresses the "read" button. The readout appears in the display window and flashes on and off as the instrument constantly checks the reading.

f. Monfore Standardizing Strain Gage. Figure 2-25 shows the Monfore gage mounted on the surface of a structure. The gage consists of a tube, a piston fitted into one end of the tube, and a small diameter elastic wire stretched inside the tube from the piston to the other end of the tube. The wire is adjusted so that it is under slight tension when the piston is in its normal position with the piston shoulders in contact with the end of the tube. The tube and piston assembly is attached to the structure by means of insert 1. Insert 2 located at distance L from insert 1, serves as a stop for the outward movement of the piston, which is caused by the application of 16 psi air pressure within the tube. The gage measures strain by monitoring changes in length L. From Figure 2-25, $L = s + d$, where s is the length of the standard and d is the total movement of the piston from the standard position s to insert 2. The change in the electrical resistance of the elastic wire as the piston is moved outward from the standardizing position until it contacts insert 2 is used to compute d. The strain of the material under test is finally computed from d/L. Since the resistance wire is not permanently stressed, creep does not affect the measurement. The range of the gage is about 3000 microstrains with a resolution of a few millionths of an inch. A standard Wheatstone bridge circuit can be used for resistance measurements.

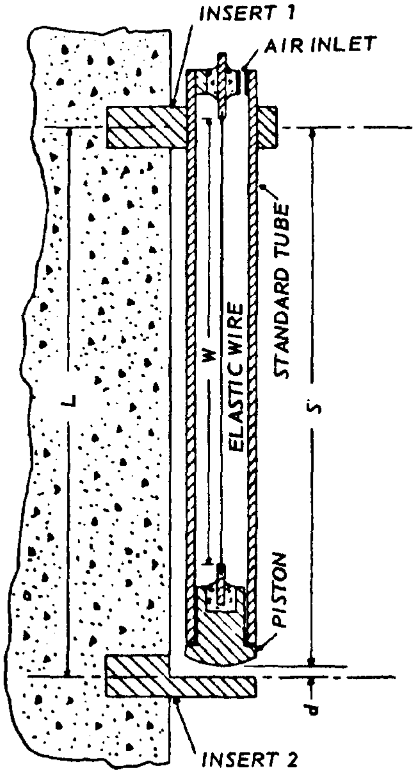


Figure 2-25. Monfore Standardizing Strain Gage. (Prepared by WES)

2-29. Linear Variable Differential Transformers.

a. Description. The linear variable differential transformers (LVDT)is a small electrical device that can be used for the measurement of displacement and strain. The unit can be used for measuring strain over a certain gage length or to measure displacement by using suitable attachments. The LVDT is an inductive device. Its only movable part, a permeable or ferromagnetic core, develops a variable coupling between the primary and the two secondary windings. The position of this core varies the voltage induced into each of two identical secondaries connected in series opposed fashion. When the core is moved off-center, a differential voltage will appear across the secondaries. The voltage is a linear function of displacement. The WES low modulus inductive strain meter, shown in Figure 2-26, utilizes an LVDT mounted in a cylindrical tube with two end plates. The gage is designed to monitor very early strains in fresh concrete as well as long-term strains.

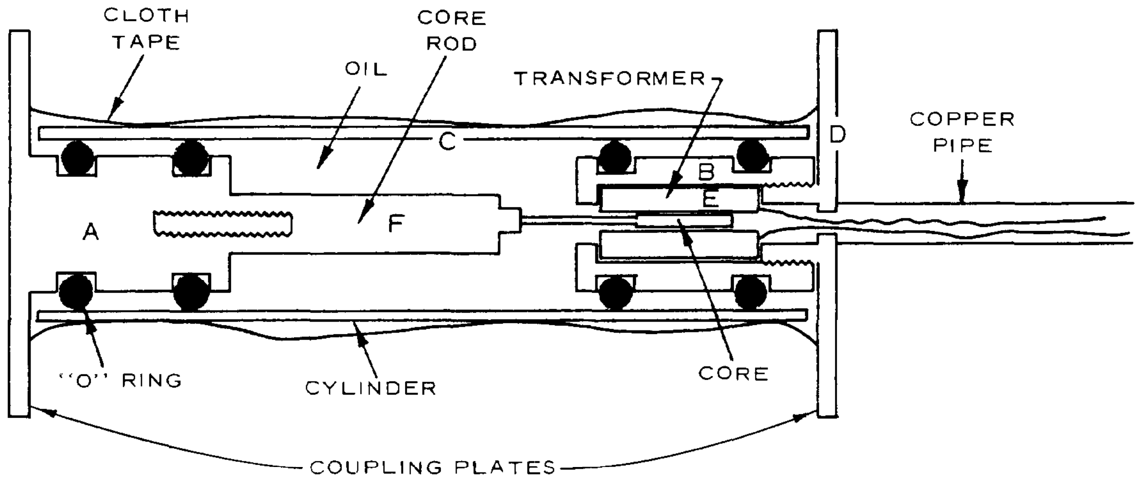


Figure 2-26. Low Modulus Linear Variable Differential Transformer Strain Meter. (Prepared by WES)

b. Voltage Requirements. The gages are available in both direct current (dc) and alternating current (ac) models. The ac model requires an exciter-demodulator, which supplies regulated ac excitation (usually at a frequency of 1 K to 3 K hertz) to the transducer, demodulates the transducer output signal, and produces a filtered dc output signal precisely proportional to mechanical input, over the full plus and minus range of the transducer. The dc model requires a regulated dc input to a self-contained solid state oscillator and a phase-sensitive demodulator. The oscillator converts the dc input to ac, exciting the primary windings of the differential transformer. The voltage induced in the two secondary windings are connected to the demodulator consisting of a full-wave bridge and a RC filter. The resulting dc output is proportional to the core displacement from the electrical center. The polarity of the voltage is a function of the direction of the core displacement with respect to the electrical center.

2-30. Resistance Strain Gage. An electrical strain gage (resistance gage) is another device used to measure strain. It is constructed such that any strain in the body to which it is bonded is accompanied by a proportional change in the resistance of the gage. Resistance gages are used for many applications because they are versatile and offer many advantages over other gages; i.e., small size, light weight, ease of attachment, sensitivity to strain, usefulness for static and dynamic strain, low cost, and easy adaptability for remote recording. The readings from these gages, directly recorded by a strain indicator utilizing a Wheatstone bridge technique, can resolve strain as accurately as one microinch per inch. The main disadvantages of the resistance-type gages are: excessive electrical drift which occurs over a long period of time; and sensitivities to ambient variables. They are not a good choice for long-term embedment because of waterproofing difficulties. Resistance gages are used successfully, however, in the fabrication of commercial pressure gages.

2-31. Stress Measuring Instruments.

a. Stress Measurements. Stress measurements can be made both directly and indirectly. Whenever possible, direct stress measurements should be made. For some applications, i.e., detecting tensile stress, it may be necessary to measure other quantities, such as strain, and then compute stress. It is sometimes desirable to provide for some strain measurements for a check or back-up for direct stress measurements and for detecting tension. The stress meters considered here are the WES pressure gage, Gloetzel pressure cell, and the vibrating wire stress gage.

b. WES Pressure Gage. The principle of operation of the WES pressure gage is similar to that of the Carlson stress meter. The diaphragm in the WES meter, shown in Figure 2-27, is filled with oil (5) rather than mercury and a bonded strain gage (7) is used to measure the deformations of the central flexible portion (6). A dummy gage (9) mounted on a free cantilever (8) serves for temperature compensation. The measuring technique for this gage is essentially the same as for any strain gage network consisting of two active arms (active strain gage and temperature compensating gage). Length of cable and effects of temperature on cable need to be taken into consideration. Like the Carlson stress gage, the WES gage is not suitable for tension measurements.

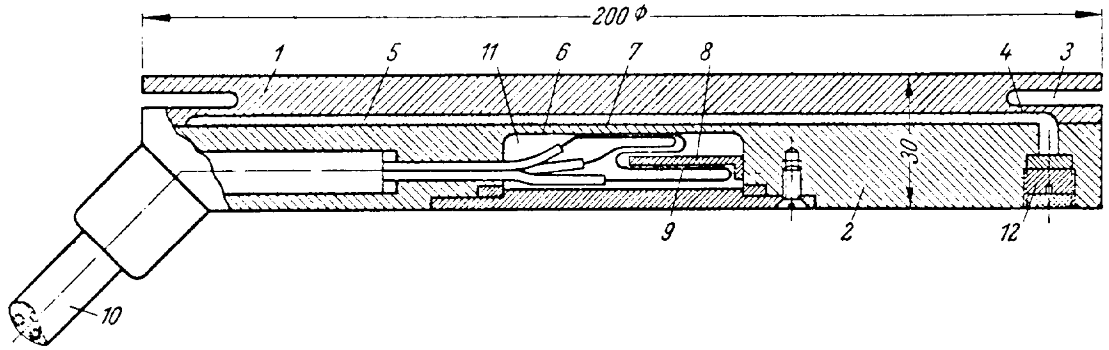
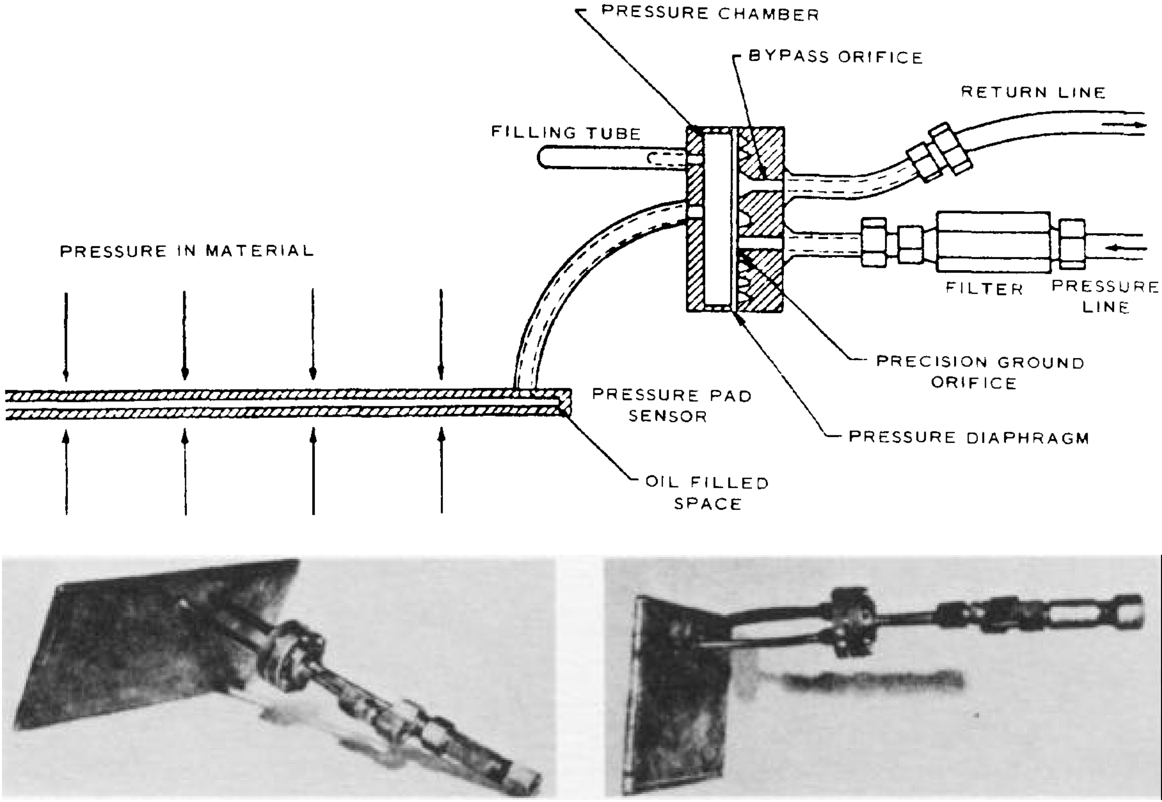


Figure 2-27. WES Pressure Gage. (Prepared by WES)

e. Gloetzel Pressure Cell.

(1) Description. The Gloetzel pressure cell is a hydraulic, direct stress measuring system based on the principle of a bypass valve. The meter, shown in Figure 2-28, consists of two disks welded together around their outer diameters. The inward-facing surface of one of the disks has circular and radial grooves. Since the disks lie against one another, a force can be transmitted through them without bending. The grooved disk has a bypass valve opening and a pressure line inlet opening. The cell is maintained in a closed configuration by the action of pressure on the sensing pad. To measure the magnitude of the pressure on the sensing pad, the hydraulic pressure in the cell delivery line is slowly increased at a constant rate. When the delivery pressure becomes equal to the pressure acting on the cell, the valve system opens, bypassing hydraulic fluid to the cell return lines. The pressure at which bypass occurs is indicated by a precise readout instrument in the delivery line.



CONCRETE STRESS CELL

Size	- 2-3/4" x 5-1/2" x 3/32" and 4" x 8" x 3/32" (others on request)
Measuring Range	- 0 - 3570 psi
Sensitivity	- 0.15 psi 1.5 psi

Figure 2-28. Gloetzel Pressure Cell. (by WES, after Terrametrics)

(2) Capabilities. The Gloetzel pressure cell operation is completely hydraulic having long-term reliability. It is a relatively low cost instrument requiring only simple readout equipment, i.e., manometer. It enables the determination of the actual stress developed in structures, e.g., concrete-stress, soils pressure, pore pressure, and total water-pressure over the measuring range of 0 to 3750 psi. It is unaffected by strains due to shrinkage, creep, and cyclic loading, especially in concrete. With minor corrections for temperature, line friction, and elevation differences between the cell and the manometer, the manometer pressure is equivalent to the pressure acting on the cell.

e. Vibrating Wire Stress Meter.

(1) The vibrating wire stress meter manufactured by Irad Gage (Figure 2-29) has been designed to monitor stress changes in rock, coal, or concrete under the most adverse environmental conditions. When prestressed into a 1-1/2-in. borehole, the cylindrical gage can sense stress changes of as little as 2 psi. The stress changes act on the gage and alter the period of the resonant frequency of a highly tensioned steel wire clamped diametrically across the gage. Because the stress meter is rigid compared to the surrounding material, conversion of the frequency readings to stress changes do not require accurate knowledge of the media modulus. Calibration charts are supplied with the gages.

(2) The stress meter can be installed in dry or water-filled boreholes at depths of up to 100 ft. It is set by means of a manually or hydraulically operated setting tool that pulls a wedge in between the gage and a platen. Like the vibrating wire strain meter, contact resistance, leakage to ground or signal cable lengths do not influence the gage readings and the signal cable needs only to be continuous in order for a reading to be made. Signal cable lengths up to a mile can be used. The frequency readings are obtained with a portable digital readout meter. Gages can be obtained for maximum readings to 10,000 psi.

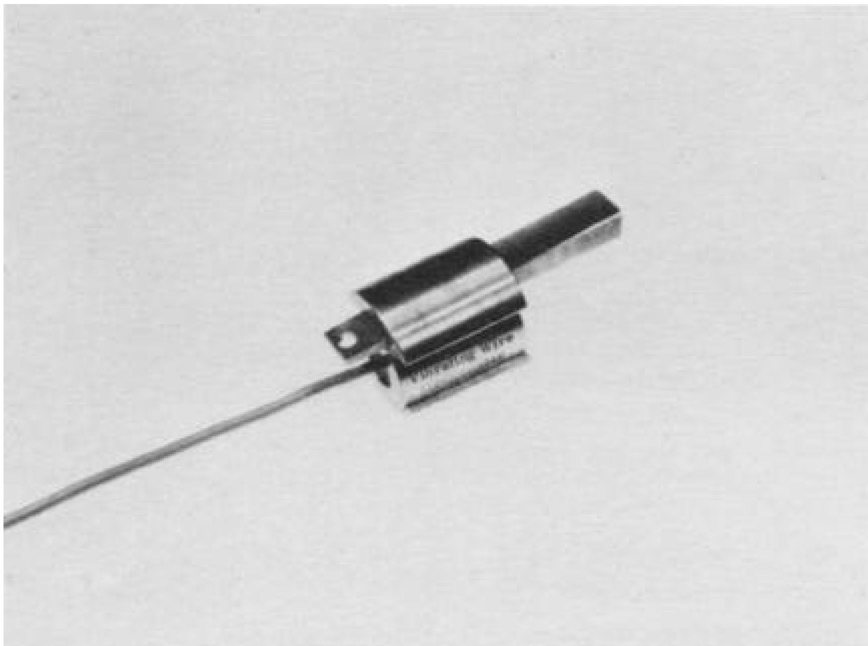
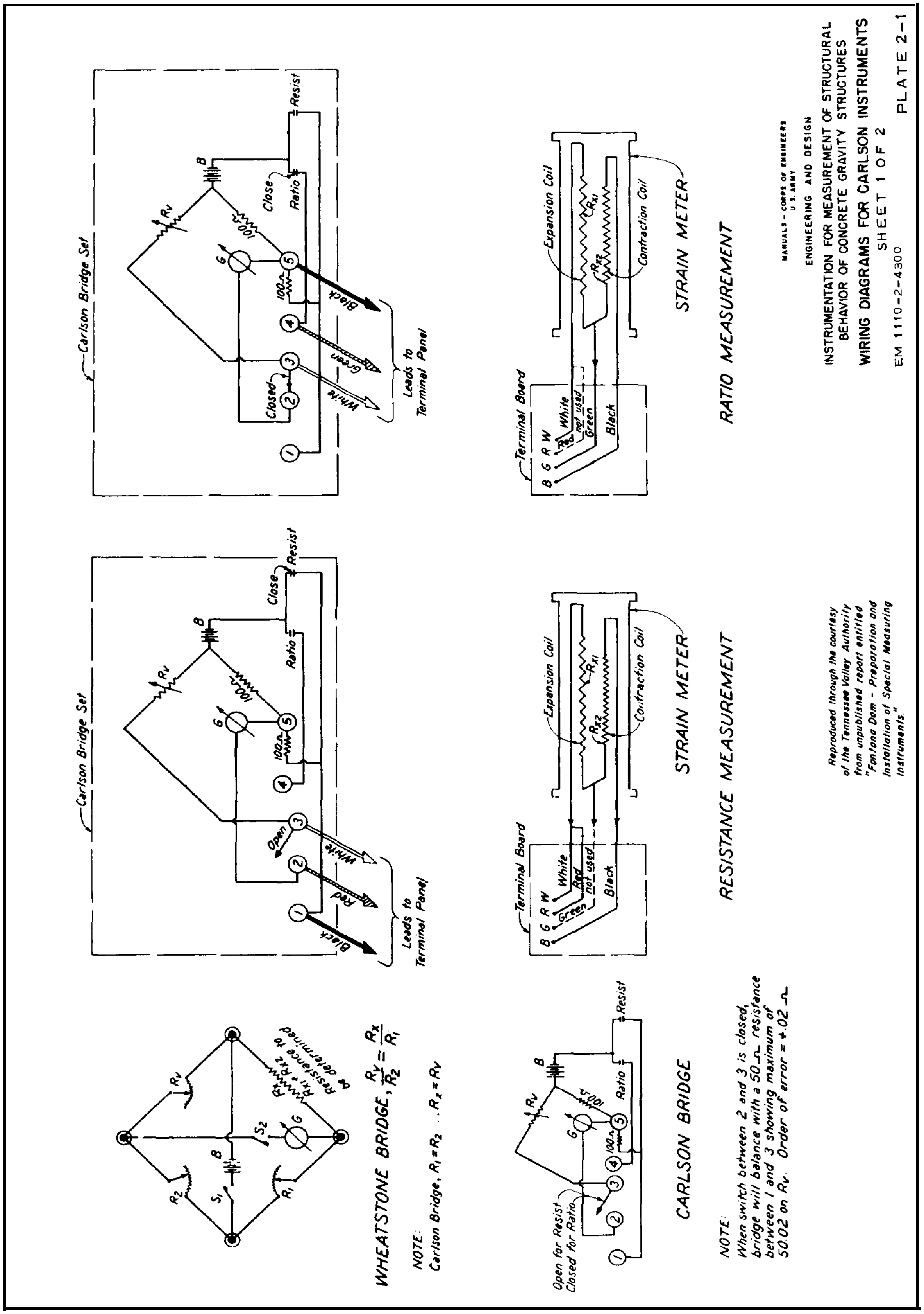


Figure 2-29. The IRAD Vibrating Wire Stressmeter (Courtesy of Irad Gage, Inc.).


WHEATSTONE BRIDGE, Rv/R2 = Rx/R1
NOTE:
Carlson Bridge, R1 = R2 ∴ Rx = Rv
Rx = Rx1 + Rx2 resistance to be determined
Rv
R2
R1
B
S1
S2
G
CARLSON BRIDGE
Open for Resist
Closed for Ratio
Resist
Ratio
100Ω
NOTE:
When switch between 2 and 3 is closed, bridge will balance with a 50 Ω resistance between 1 and 3 showing maximum of 50.02 on Rv. Order of error = ±.02 Ω
Carlson Bridge Set
Close
Open
Closed
Black
Red
Green
White
Leads to Terminal Panel
Terminal Board
B G R W
not used
Expansion Coil
Contraction Coil
Rx1
Rx2
STRAIN METER
RESISTANCE MEASUREMENT
RATIO MEASUREMENT
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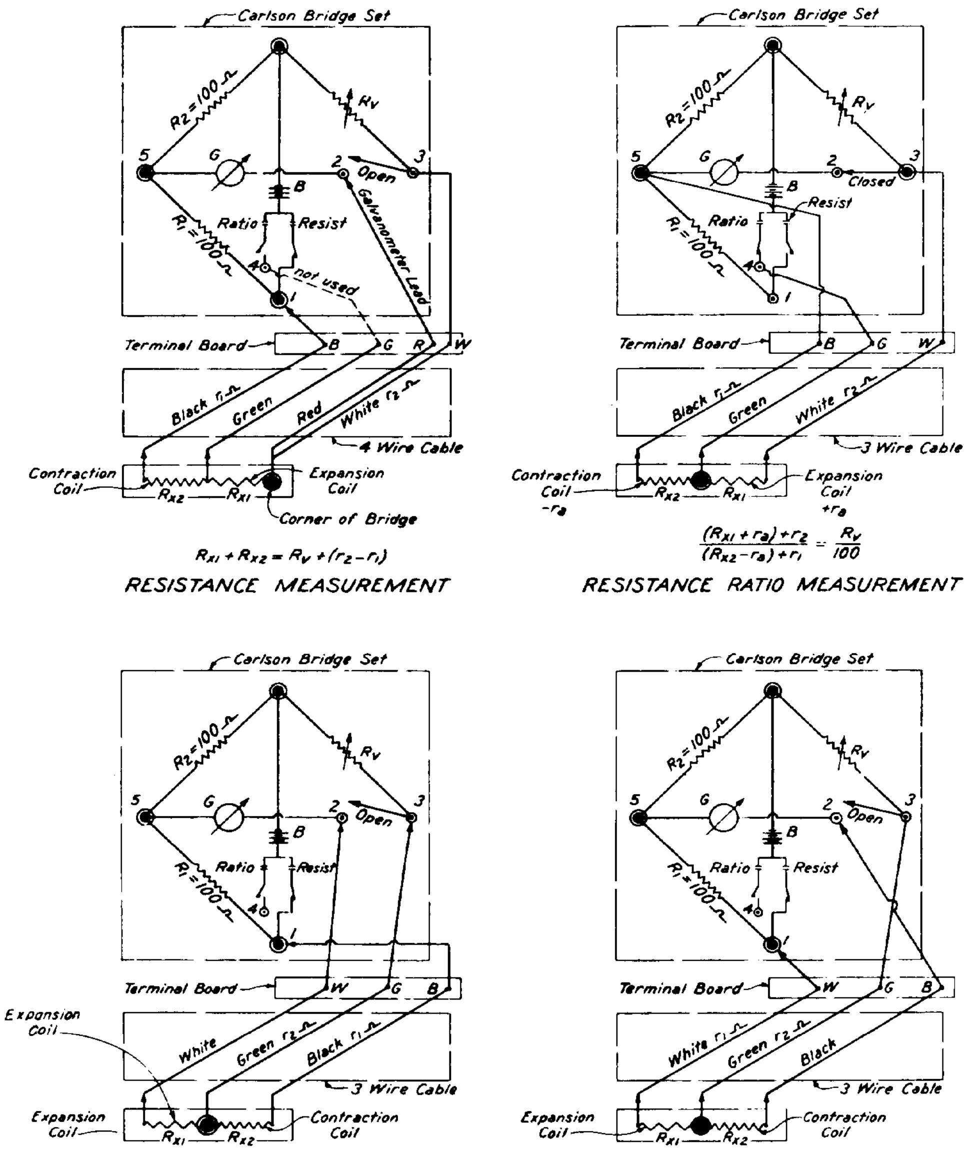
MANUALS - CORPS OF ENGINEERS
U.S. ARMY
ENGINEERING AND DESIGN
INSTRUMENTATION FOR MEASUREMENT OF STRUCTURAL BEHAVIOR OF CONCRETE GRAVITY STRUCTURES
WIRING DIAGRAMS FOR CARLSON INSTRUMENTS
SHEET 1 OF 2
EM 1110-2-4300
PLATE 2-1



$R_{X1} + R_{X2} = R_V + (r_2 - r_1)$

RESISTANCE MEASUREMENT

$\frac{(R_{X1} + r_a) + r_2}{(R_{X2} - r_a) + r_1} = \frac{R_V}{100}$

RESISTANCE RATIO MEASUREMENT

$R_{X2} + (r_1 - r_2) = R_V$

RESISTANCE MEASUREMENT
CONTRACTION COIL

$R_{X1} + (r_1 - r_2) = R_V$

RESISTANCE MEASUREMENT
EXPANSION COIL

SYMBOLS:

● Corners of Bridge

●3 Corners of Bridge & Terminal Post

⊙2 Terminal Post

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MANUALS - CORPS OF ENGINEERS
U S ARMY

ENGINEERING AND DESIGN

INSTRUMENTATION FOR MEASUREMENT OF STRUCTURAL BEHAVIOR OF CONCRETE GRAVITY STRUCTURES

WIRING DIAGRAMS FOR CARLSON INSTRUMENTS
SHEET 2 OF 2

EM 1110-2-4300

PLATE 2-2

MEASUREMENTS TAKEN TO CORRECT INSTRUMENT CALIBRATIONS

Carlson Number	Wire resistances				Coil resistances at splice					Coil resistances at end					Ratio at splice	Ratio at end	Temperature
	Red	Black	White	Green	G W	G B	B W	B W G	W B G	G W	G B	B W	B W G	W B G			
1	0. 40	0. 40	0. 38	0. 40	38. 58	37. 55	76. 03	37. 51	38. 53	39. 37	38. 36	76. 78	37. 51	38. 51	1. 0274	1. 0264	75. 98
2	. 46	. 46	. 44	. 46	38. 43	38. 16	76. 47	38. 12	38. 38	39. 38	39. 14	77. 49	38. 15	38. 39	1. 0062	1. 0062	76. 53
3	. 57	. 54	. 52	. 54	37. 97	37. 67	75. 53	37. 62	37. 92	39. 04	38. 76	76. 58	37. 62	37. 90	1. 0077	1. 0071	75. 48
4	. 88	. 91	. 87	. 92	38. 34	37. 96	76. 23	37. 93	38. 32	40. 19	39. 84	78. 11	37. 92	38. 28	1. 0102	1. 0093	76. 28
JM-34	. 42	. 39	. 38	. 40	27. 61	28. 05	55. 49	28. 02	27. 59	28. 41	28. 87	56. 35	28. 02	27. 57	. 9841	. 9839	55. 57
-31	. 79	. 79	. 81	. 83	27. 66	28. 29	55. 81	28. 26	27. 63	29. 33	29. 95	57. 47	28. 23	27. 61	. 9775	. 9786	55. 82
21	. 14	. 14	. 14	. 14	27. 09	27. 76	54. 67	27. 73	27. 06	27. 38	28. 05	54. 99	27. 73	27. 06	. 9755	. 9756	54. 71
25	. 24	. 24	. 24	. 24	27. 34	27. 82	54. 97	27. 78	27. 31	27. 85	28. 34	55. 52	27. 78	27. 31	. 9827	. 9827	55. 01
36	. 62	. 62	. 62	. 62	28. 08	28. 57	56. 48	28. 54	28. 06	29. 34	29. 82	57. 75	28. 54	28. 06	. 9829	. 9831	56. 50
43	. 87	. 88	. 87	. 87	26. 97	27. 52	54. 34	27. 50	26. 94	28. 73	29. 29	56. 15	27. 51	26. 94	. 9794	. 9799	54. 38
46	1. 23	1. 23	1. 18	1. 23	27. 36	27. 48	54. 69	27. 45	27. 33	29. 77	29. 95	57. 11	27. 44	27. 26	. 9952	. 9937	54. 67
144	. 37	. 38	. 36	. 38	34. 17	33. 74	67. 82	33. 72	34. 14	34. 94	34. 53	68. 63	33. 72	34. 13	1. 0126	1. 0119	67. 86
2	. 38	. 39	. 39	. 40	33. 38	32. 92	66. 28	32. 96	33. 34	34. 20	33. 82	67. 13	32. 95	33. 34	1. 0114	1. 0116	66. 33
19	------	. 40	. 39	. 38	32. 69	32. 64	65. 23	32. 62	32. 67	33. 50	33. 45	66. 11	32. 64	32. 68	1. 0015	1. 0014	------
38	------	. 39	. 39	. 38	33. 06	33. 02	65. 98	33. 00	33. 03	33. 87	33. 83	66. 87	33. 02	33. 06	1. 0009	1. 0009	------
26	------	. 39	. 38	. 37	33. 59	33. 71	67. 24	33. 68	33. 56	34. 38	34. 39	68. 03	33. 69	33. 57	. 9964	. 9964	------
22	------	. 39	. 39	. 38	33. 51	33. 29	66. 70	33. 26	33. 47	34. 29	34. 09	67. 54	33. 27	33. 48	1. 0061	1. 0061	------
131	. 29	. 29	. 29	. 29	33. 54	33. 60	67. 04	33. 58	33. 50	34. 14	34. 22	67. 71	33. 58	33. 51	. 9978	. 9978	67. 11
141	------	. 31	. 31	. 30	33. 88	33. 26	67. 08	33. 23	33. 85	34. 52	33. 90	67. 73	33. 24	33. 86	1. 0186	1. 0185	------
147	------	. 30	. 30	. 29	33. 69	33. 51	67. 14	33. 48	33. 67	34. 33	34. 14	67. 80	33. 50	33. 69	1. 0056	1. 0054	------

(Prepared by **WES**)

COMPUTATION OF CALIBRATION CORRECTIONS CARLSON-TYPE INSTRUMENTS

	Carlson number	Original calibration constant	Resistance at instrument	Resistance at end	Corrected calibration constant	Given resistance at 0° F.	Resistance				Corrected resistance at 0° F.	Given temperature factor	Corrected temperature equation	Notes
							White wire	Black wire	Green wire	Correction				
		(1)	(2)	(3)	(1)×(3)/(2)	(Ro)					(Ro)	(°F./ohm)		
Stress meters	1	5. 6 psi	76. 03	76. 78	5. 66 psi	66. 08	0. 38	0. 40		0. 02	66. 10	7. 84	$t=(R_t-66.10)\ 7.84$	4-cond. cable.
	2	5. 4	76. 47	77. 49	5. 47	66. 40	. 44	. 46		. 02	66. 42	7. 80	$t=(R_t-66.42)\ 7.82$	Do.
	3	6. 3	75. 53	76. 52	6. 39	66. 00	. 52	. 54		. 02	66. 02	7. 85	$t=(R_t-66.02)\ 7.85$	Do.
	4	5. 7	76. 23	78. 11	5. 84	66. 15	. 87	. 91		. 04	66. 19	7. 83	$t=(R_t-66.19)\ 7.78$	Do.
Joint meters	JM-34	. 00053	55. 49	56. 35	. 000538	48. 36	. 38	. 39		. 01	48. 37	10. 72	$t=(R_t-48.37)\ 10.71$	Do.
	JM-31	. 00051	55. 81	57. 47	. 000525	48. 63	. 81	. 79		-. 02	48. 61	10. 79	$t=(R_t-48.61)\ 10.66$	Do.
	JM-21	. 00056	54. 67	54. 99	. 000563	47. 29	. 14	. 14		0	47. 29	10. 96	$t=(R_t-47.29)\ 10.96$	Do.
	JM-25	. 00053	54. 97	55. 52	. 000535	47. 70	. 24	. 24		0	47. 70	10. 86	$t=(R_t-47.70)\ 10.86$	Do.
	JM-36	. 00051	56. 48	57. 75	. 000521	48. 38	. 62	. 62		0	48. 38	10. 71	$t=(R_t-48.38)\ 10.71$	Do.
	JM-43	. 00056	54. 34	56. 15	. 000579	47. 80	. 87	. 88		. 01	47. 81	10. 84	$t=(R_t-47.81)\ 10.84$	Do.
	JM-46	. 00054	54. 69	57. 11	. 000564	47. 51	1. 18	1. 23		. 05	47. 56	10. 91	$t=(R_t-47.56)\ 10.90$	Do.
Strain meters	144	3. 70	67. 82	68. 63	3. 74	57. 95	. 36	. 38		. 02	57. 97	8. 94	$t=(R_t-57.97)\ 8.94$	Do.
	2	3. 70	66. 28	67. 13	3. 75	57. 84	. 39	. 39		0	57. 84	8. 96	$t=(R_t-57.84)\ 8.96$	Do.
	131	3. 75	67. 04	67. 71	3. 79	57. 90	. 29	. 29		0	57. 90	8. 95	$t=(R_t-57.90)\ 8.95$	Do.
	19	3. 75	65. 23	66. 11	3. 80	57. 73	. 53	. 56	. 57	. 05	57. 78	8. 98	$t=(R_t-57.78)\ 8.98$	3-cond. cable.
	38	3. 75	65. 98	66. 87	3. 80	57. 81	. 33	. 32	. 32	-. 01	57. 80	8. 96	$t=(R_t-57.80)\ 8.96$	Do.
	26	3. 70	67. 24	68. 03	3. 74	57. 85	. 68	. 69	. 68	-. 01	57. 84	8. 96	$t=(R_t-57.84)\ 8.96$	Do.
	22	3. 75	66. 70	67. 54	3. 80	57. 92	. 12	. 12	. 13	. 02	57. 94	8. 95	$t=(R_t-57.94)\ 8.95$	Do.
	141	3. 65	67. 08	67. 73	3. 69	57. 96	. 94	. 97	. 96	. 01	57. 97	8. 94	$t=(R_t-57.97)\ 8.94$	Do.
	147	3. 70	67. 14	67. 80	3. 74	57. 77	1. 21	1. 18	1. 18	-. 03	57. 74	8. 97	$t=(R_t-57.74)\ 8.97$	Do.

(Prepared by WES)

Plate 2-4

________________ PROJECT

FIELD READINGS ON EMBEDDED INSTRUMENTS

Instr. No.	Previous readings		Date	Time	Resist.	Ratio	Obs.
	Resist.	Ratio					
T-1							
2							
3							
4							
5							
6							
7							
SM-1							
2							
3							
4X							
JM-1							
2							
3							
4							
5							
6							
PP-1							
2							
3							
4							
5							
6							
7							
8							

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_______________ PROJECT

PORE PRESSURE CELL DATA SHEET

Pore pressure cell No. ______________________________ Sheet ______

Location ____

Calibration data:

Meter resistance at (A)* ° F.. (B)* ohms.
Change in temperature per ohm change in resistance.......................... (C)* ° F.
Ratio at zero stress.. — %.
Original calibration constant.. (*) psi/.01 % ratio change.
Calibration constant corrected for leads.. (D) psi/.01 % ratio change.
Resistance of leads at __° F.. ohms (pair).

1	2	3	4	5	6	7	8	9	10
Date	Time	Total resist., ohms	Lead ohms	Meter resist., ohms	Temp., ° F.	Resist. ratio, %	Change in ratio, %	Indicated hydrost. pressure, psi	Remarks

*Furnished by manufacturer.

EXPLANATION:

Cols. 3 to 7, inclusive—Similar to corresponding columns on stress meter data sheet. No temperature corrections are made; but the temperature data is of general interest and provides a possible means for detecting faulty operation of the strain-measuring units.

Col. 8—Total change in resistance ratio (column 7) from a selected initial value, usually the first reading after the concrete has hardened or at about 24 hours age. Proper algebraic sign should be shown.

Col. 9—Multiply values in column 8 by the corrected calibration constant (D). Negative values of the ratio changes (column 8) indicate positive hydrostatic pressures. Except for minor ratio variations prior to the development of significant hydrostatic pressures, the pore pressure cell will not respond reliably to negative pressures, and all entries in column 9 will represent hydrostatic pressures above the oil pressure in the cell chamber (approximately atmospheric).

(Prepared by WES)

__________________ PROJECT

STRESS METER DATA SHEET

Stress meter No. ____ **Sheet** ______________

Location: ____

Calibration data:

Meter resistance at (A)*° F________________________________ (B)* ohms
Change in temperature per ohm change in resistance ________________ (C)* ° F
Ratio at zero stress________________________________ %
Original calibration constant________________________________ (D)* psi/.01 ratio % change.
Calibration constant corrected for leads________________________________ (E) psi/.01 ratio % change.
Resistance of leads at ___° F________________________________ — ohms (per pair)

Temperature correction=—[(80T/D+6.7)10⁻⁶—K]E·F 80T/D=___*—; K=—; F=___*
=—___E(10⁻⁶)psi per 1° F. temp. rise

1	2	3	4	5	6	7	8	9	10	11	12	13	14
Date	Time	Total resist., ohms	Lead resist., ohms	Meter resist., ohms	Temp., ° F.	Resist. ratio, %	Change in ratio, %	Indic. stress psi	Est. E. million psi	Corr. per ° F., psi	Total temp. corr., psi	Actual stress, psi	Remarks

*Furnished by manufacturer

EXPLANATION:

Col. 3—Total resistance of meter as measured in field. With 4-conductor cable the meter resistance is measured directly, and this column may be left blank.

Col. 4—Resistance of the white and black conductors, as measured directly during the splicing operations. Or a reasonably accurate value may be determined by subtracting the total resistance of the contraction and expansion coils measured in series from the sum of the resistances of the contraction and expansion coils measured separately.

Col. 5—Resistance of meter excluding cable leads. It is obtained by subtracting column 4 from column 3. With 4-conductor cable the meter resistance is measured directly.

Col. 6—Temperature of meter, obtained by subtracting (B) from the meter resistance in column 5, multiplying by (C), and adding to (A).

Col. 7—The resistance ratio of the meter as measured with the test set.

Col. 8—Column 7 minus the resistance ratio at zero stress. The "zero ratio" is determined by taking several readings during the first several hours after the meter is placed, and adopting a value which is representative. Since the concrete will be under little stress and highly plastic at this early age, the measured resistance ratios will vary but little from the zero stress ratio. Proper algebraic signs must be shown with the numerical values.

Col. 9—Column 8 values multiplied by calibration constant E. Negative resistance ratio changes (column 8) are associated with the development of compressive stress, which, by custom, is considered a positive quantity.

Col. 10—This column and the next two columns develop a correction for temperature to be applied to the indicated stress (column 9), which is necessary since the meter responds to stress resulting from differences in thermal expansion between the meter and the surrounding concrete. In column 10 is entered estimated values of the sustained modulus of elasticity of the concrete. This is a reduced modulus of elasticity which includes the effect of creep over the period of time covered by the temperature correction. A value of one-half of the ordinary modulus of elasticity is frequently used.

Col. 11—Computed from the temperature correction equation given above, using a value for the thermal coefficient of expansion of the concrete obtained from laboratory tests or estimated from other data, and values of E from column 10.

Col. 12—The net change in temperature from the initial reference temperature multiplied by column 11 values. Since the magnitude of the correction is usually small in comparison to applied or load stresses, precise values in columns 10 and 11 are not essential. The algebraic sign of the correction is significant, and signs of the temperature change and temperature correction must be observed.

Col. 13—Actual stress, obtained by adding values in column 12 to values in column 9, observing the signs of the temperature corrections in column 12. A temperature rise causes the stress meter to expand more than the concrete (usually) and results in an indicated compression response by the stress meter in addition to any load-produced stress which may exist. An indicated compressive stress then must be reduced, and vice versa.

(Prepared by WES)

Plate 2-7

__________ PROJECT

STRAIN METER DATA SHEET

Strain meter No. ______________________________ Sheet __________

Location ____

Calibration data:

Meter resistance at (A)*° F.. (B)* ohms.
Change in temperature per ohm change in resistance.......................... (C)* ° F.
Original calibration constant.. (*) millionths/.01% ratio change.
Calibration constant corrected for leads.. (D) millionths/.01% ratio change.
Resistance of leads at __° F.. ohms (pair).
Temperature correction for meter.. (E)* millionths/° F.
Concrete coefficient of thermal expansion.. (F) millionths/° F.

1	2	3	4	5	6	7	8	9	10	11	12	13	14
Date	Time	Total resist., ohms	Lead resist., ohms	Meter resist., ohms	Temp. ° F.	Resist. ratio, %	Change in ratio, %	Indicated unit length change, millionths	Correction for meter expansion, millionths	Actual unit length change, millionths	Correction for concrete expansion, millionths	Actual strain, millionths	Remarks

*Furnished by manufacturer.

EXPLANATION:

Col. 3 to 7, inclusive—Similar to corresponding columns on the stress meter data sheet.

Col. 8—Total change in resistance ratio (column 7) from a selected initial value. This initial reference value is usually taken as the first reading made after the concrete has attained its final set. Usually it is at 12 or 24 hours age. The proper algebraic sign must be indicated.

Col. 9—Multiply the values in column 8 by the corrected calibration constant (D). The algebraic signs of the column 8 values are carried over into column 9. An increase in resistance ratio indicates an increase in length, and vice versa.

Col. 10—The correction for thermal expansion or contraction of the meter frame is computed by multiplying the difference between a base reference temperature and the measured meter temperature (including the proper algebraic sign) by the given temperature correction factor (E). The base reference temperature selected is not significant, since only strain differences are considered in the application of the actual strain results. A base reference temperature of 70° F. is frequently used. The algebraic sign of the correction is important, a rise in measured meter temperature will result in a potentional expansion of the meter frame, and the correction must be added to the indicated length change to obtain the actual length change.

Col. 11—The algebraic sum of the values in column 9 and column 10. This column represents the actual length changes of the concrete due to all causes.

Col. 12—Changes in temperature cause potential length changes in the concrete, and the derived length changes in column 11 are corrected to compensate for this effect. The correction is equivalent to subtracting the thermal length change which would have taken place had the concrete been unrestrained, and is always opposite in sign to the meter frame correction. Its value is determined in a manner similar to that followed for column 10, using a base reference temperature (usually 70° F.) and the concrete coefficient of thermal expansion (F) taken from laboratory data or estimated from other sources. An increase in temperature (column 6) results in a negative value for the column 12 figure, and a decrease in temperature, a positive value.

Col. 13—The algebraic sum of the values in columns 11 and 12.

Col. 14—Identify the reading selected as the no-stress or initial condition, and give age of concrete for that date and hour.

(Prepared by WES)

Plate 2-8

____________________ PROJECT

RESISTANCE THERMOMETER DATA SHEET

Resistance thermometer No. ____________________ Sheet ________

Location ______________________________

Calibration data:

Meter resistance at (A)* ° F.................................... (B)* ohms
Calibration constant.................................... (C)* ohm change/°F
Corrected meter resistance at (A) ° F.................................... (D) ohms
Resistance of leads at__° F.................................... ohms (pair)

1	2	3	4	1	2	3	4
Date	Time	Meter Resist., ohms	Temp., ° F.	Date	Time	Meter Resist., ohms	Temp., ° F.

*Furnished by manufacturer.

EXPLANATION:

Calibration Data—Meters are usually so wound as to have 39.00 ohms resistance (B) at 0° F. (A), which, for the quality of copper wire used, provides a calibration constant (C) of 0.10 ohm change per degree F. change. The corrected meter resistance (D) is obtained from the given value (B) during the field calibration check.

Col. 3—Measured 3-wire resistance of meter.

Col. 4—Temperature of meter, obtained by subtracting corrected meter resistance (D) from resistances in column 3, multiplying result by calibration constant (C), and adding to base temperature (A).

(Prepared by WES)

Plate 2-9

______________ PROJECT

JOINT METER DATA SHEET

Joint meter No. ______________________________ Sheet ______

Location ______________________________

Calibration data:

Meter resistance at (A)* ° F. .... (B)* ohms.
Change in temperature per ohm change in resistance .... (C)* ° F.
Ratio in closed position .... %.
Original calibration constant .... (*) in./.01 % ratio change.
Calibration constant corrected for leads .... (D) in./.01 % ratio change.
Resistance of leads at ___ ° F. .... ohms (pair).

1	2	3	4	5	6	7	8	9	10
Date	Time	Total resist., ohms	Lead ohms	Meter resist., ohms	Temp., ° F.	Resist. ratio, %	Change in ratio, %	Indicated movement, inches	Remarks

*Furnished by manufacturer.

EXPLANATION:

Cols. 3 to 7, inclusive—Similar to corresponding columns on stress meter data sheet. Since the magnitude of thermal length changes of the meter and concrete due to changes in temperature are insignificantly small relative to the joint movements being measured and the range of the meter, no temperature correction is made. Temperature data is of general interest and provides a means for detecting faulty operation of the strain measuring unit.

Col. 8—Total change in resistance ratio (column 7) from a selected initial value when the joint is known to be closed. This is usually taken at about 24 hours after the concrete has been placed. The proper algebraic sign must be shown.

Col. 9—Multiply values in column 8 by the corrected calibration constant (D). The algebraic signs of column 8 are carried over into column 9, positive values indicating an opening of the joint with respect to the initial position, and vice versa.

(Prepared by WES)

_______________ PROJECT

PORE PRESSURE CELL DATA SHEET

Pore pressure cell No. ______________________ **Sheet** ______

Location ______________________

Calibration data:

Meter resistance at 0 * ° **F** ---------- 50.16 * **ohms.**
Change in temperature per ohm change in resistance ---------- 11.10 * ° **F.**
Ratio at zero stress ---------- 96.79 %.
Original calibration constant ---------- 5.25 * **psi/.01 % ratio change.**
Calibration constant corrected for leads ---------- 5.68 **psi/.01 % ratio change.**
Resistance of leads at 70° **F** ---------- 6.30 **ohms (pair).**

1	2	3	4	5	6	7	8	9	10
Date	Time	Total resist., ohms	Lead ohms	Meter resist., ohms	Temp., ° F.	Resist. ratio, %	Change in ratio, %	Indicated hydrost. pressure, psi	Remarks
2-5-80	8 am	62.85	6.30	56.55	70.9	96.79	0	0	at placement
2-6-80	8 am	63.08	6.35	56.73	72.9	96.77	-0.02	11.4	24 hrs-age
2-7-80	8 am	63.65	6.51	57.14	77.5	96.77	-0.02	11.4	

EXAMPLE CALCULATIONS

Column 1 Self explanatory

Column 2 Self explanatory

Column 3 Total resistance of meter as measured in the field. This reading is taken directly from the readout box (with selector switched to resistance) and includes resistance for both meter and associated lead cable.

Column 4 The resistance of the lead wires when disconnected from the meter, or if the leads are connected to the meter, measure resistance between the red-white terminals and between the red-black terminals. Sum these two resistances and subtract the sum from the resistance between the black-white terminals. If the meter has a 4-conductor cable it can be read directly.

Column 5 (Value in column 3) - (Value in column 4)
62.85 - 6.30 = 56.55, 63.08 - 6.35 = 56.73, and 63.65 - 6.51 = 57.14

Column 6 The temperature reading of the meter is calculated by subtracting the calibration meter resistance (usually that at 0°F) from the meter resistance in col. 5 and then multiplying by the change in temperature per ohm change in resistance.
(56.55 - 50.16)(11.10) = 70.9, (56.73 - 50.16)(11.10) = 72.9, (57.14 - 50.16)(11.10) = 77.5
If the calibration temperature is not 0°F then the above calculated temperature is added to the temperature at which the meter was calibrated.

Column 7 Reading as taken directly from the test set (with selector switch set to ratio) if the ratio is greater than 100%, some instruments assume the presence of the hundreds column and only measure XX.XX

Column 8 (Present value of column 7) - (Ratio in closed position)
96.79 - 96.79 = 0, 96.77 - 96.79 = -0.02, 96.77 - 96.79 = -0.02

Column 9 (Value in column 8)(Calibration constant corrected for leads)
(-0.02)(5.68) = 11.4

* Data supplied by Gage Manufacturer.
** Readings must be taken at placement to obtain a reference pressure.

(Prepared by WES)

Plate 2-11

_______________ PROJECT

STRESS METER DATA SHEET

Stress meter No. ____________________ **Sheet** ____________

Location: ____________________

Calibration data:

Meter resistance at 0 *° **F** .... 59.44 * ohms
Change in temperature per ohm change in resistance .... 9.44 * ° F
Ratio at zero stress .... 101.72 %
Original calibration constant .... 5.25 * psi/.01 ratio % change.
Calibration constant corrected for leads .... 5.68 psi/.01 ratio % change.
Resistance of leads at 70 ° **F** .... 5.48 ohms (per pair)

Temperature correction $= -[(80T/D + 6.7)10^{-6} - K]E \cdot F$ $\quad 80T/D = \underline{2.0}$ * —; $K = 5.5 \times 10^{-6}$
$= -$ ___ $E(10^{-6})$ psi per 1° F. temp. rise $\quad F = 0.07$ *

1	2	3	4	5	6	7	8	9	10	11	12	13	14
Date	**Time**	**Total resist., ohms**	**Lead resist., ohms**	**Meter resist., ohms**	**Temp., ° F.**	**Resist. ratio, %** (101.72)	**Change in ratio, %**	**Indic. stress psi**	**Est. E. million psi**	**Corr. per ° F., psi**	**Total temp. corr., psi**	**Actual stress, psi**	**Remarks**
2-5-80	8 am	72.61	5.5	67.11	72.4	101.73	+0.01	-6	1.0	-0.2			
2-6-80	8 am	73.43	5.61	67.82	79.1	101.70	-0.02	+11	1.1	-0.2	0	11	24 hr-age
2-7-80	8 am	73.44	5.3	68.14	82.1	101.71	-0.01	+6	1.2	-0.3	-1	5	

EXAMPLE CALCULATIONS

Column 1 Self explanatory

Column 2 Self explanatory

Column 3 Total resistance of meter as measured in the field. This reading is taken directly from the readout box (with selector switched to resistance) and includes resistance for both meter and associated lead cable.

Column 4 The resistance of the lead wires when disconnected from the meter, or if the leads are connected to the meter, measure resistance between the red-white terminals and between the red-black terminals. Sum these two resistances and subtract the sum from the resistance between the black-white terminals. If the meter has a 4-conductor cable it can be read directly.

Column 5 (Value in column 3) - (Value in column 4)
72.61 - 5.5 = 67.11, 73.43 - 5.61 = 67.82, 73.44 - 5.3 = 68.14

Column 6 The temperature reading of the meter is calculated by subtracting the calibration meter resistance (usually that at 0°F) from the meter resistance in col. 5 and then multiplying by the change in temperature per ohm change in resistance.
(67.11 - 59.44) 9.44 = 72.40, (67.82 - 59.44) (9.44) = 79.11, (68.14 - 59.44) 9.44 = 82.12
If the calibration temperature is not 0°F then the above calculated temperature is added to the temperature at which the meter was calibrated.

Column 7 Reading directly as taken from the test set. On some test sets the 100 is assumed and the meter would read, for example, 01.73

Column 8 (Most recent value of column 7) - (Zero stress ratio)
101.73 - 101.72 = +0.01, 101.70 - 101.72 = -0.02, 101.71 - 101.72 = -0.01

Column 9 (Value in column 8) (Corrected calibration constant)
(0.01%)(5.68 millionths/.01%) = -6 millionths
(0.02%)(5.68 millionths/.01%) = +11 millionths
(0.01%)(5.68 millionths/.01%) = +6 millionths

Column 10 Estimated value of modulus of elasticity (including effects of creep)

Column 11 Correction calculated from temperature correction data at the head of the sheet
For example: Value in col. 11 on 2-7-80
$-[(80T/D + 6.7)10^{-6} - K](E)(F) = -[(2.0 + 6.7)10^{-6} - (5.5)10^{-6}](1.2)(0.07) = .3 \times 10^{-6}$

Column 12 (Temperature in col. 6-assumed reference temp**)(Value in column 11)
(79.1 - 79.1)(-0.2) = 0, and (82.1-79.1)(-0.2)= -1

Column 13 (Value in column 9) + (Value in column 12)
11 + 0 = 11, and 6 + (-1) = 5

* Data supplied by Gage Manufacturer.
** In this example temp at 24 hrs is reference.

(Prepared by **WES**)

Plate 2-12

__________ PROJECT

STRAIN METER DATA SHEET

Strain meter No. ______________________________ Sheet __________

Location ______________________________

Calibration data:

Meter resistance at 0*° F. .... 56.10* ohms.
Change in temperature per ohm change in resistance .... 8.61* ° F.
Original calibration constant .... 3.82* millionths/.01% ratio change.
Calibration constant corrected for leads .... 3.98 millionths/.01% ratio change.
Resistance of leads at 70 ° F. .... 2.61 ohms (pair).
Temperature correction for meter .... 7.5 * millionths/° F.
Concrete coefficient of thermal expansion .... 5.5 millionths/° F.

1	2	3	4	5	6	7	8	9	10	11	12	13	14
Date	Time	Total resist., ohms	Lead resist., ohms	Meter resist., ohms	Temp. ° F.	Resist. ratio, %	Change in ratio, %	Indicated unit length change, millionths	Correction for meter expansion, millionths	Actual unit length change, millionths	Correction for concrete expansion, millionths	Actual strain, millionths	Remarks
2-5-80	9 am	66.91	2.61	64.30	70.60	100.97		0	+4	+4	-3	+1	age 24 hrs
2-6-80	9 am	67.36	2.63	64.73	74.30	100.91	-0.06	-24	+32	+8	-23	-15	

EXAMPLE CALCULATIONS

Column 1 Self explanatory

Column 2 Self explanatory

Column 3 Total resistance of meter as measured in the field. This reading is taken directly from the readout box (with selector switched to resistance) and includes resistance for both meter and associated lead cable.

Column 4 The resistance of the lead wires when disconnected from the meter, or if the leads are connected to the meter, measure resistance between the red-white terminals and between the red-black terminals. Sum these two resistances and subtract the sum from the resistance between the black-white terminals. If the meter has a 4-conductor cable it can be read directly

Column 5 (Value in column 3) - (Value in column 4)
66.91 - 2.61 = 64.30, and 67.36 - 2.63 = 64.73

Column 6 The temperature reading of the meter is calculated by subtracting the calibration meter resistance (usually that at 0°F) from the meter resistance in col. 5 and then multiplying by the change in temperature per ohm change in resistance.
(64.30 - 56.10)(8.61) = 70.60, and (64.73 - 56.10)(8.61) = 74.30
If the calibration temperature is not 0°F then the above calculated temperature is added to the temperature at which the meter was calibrated.

Column 7 Reading directly as taken from the test set. On some test sets the 100 is assumed and the meter would read, for example, 00.97

Column 8 (Most recent value of column 7) - (Zero stress ratio)
100.91 - 100.97 = -0.06

Column 9 (Value in column 8)(Corrected calibration constant)
(-0.06%)(3.98 millionths/.01%) = -24 millionths

Column 10 (Temp. in Column 6. - Reference temp.)(Temp. correction for meter)
(70.60 - 70.00)(7.5) = +4.5 millionths, and (74.3 - 70.00)(7.5) = +32 millionths

Column 11 (Value in column 10) + (Value in column 11)
0 + (+4) = +4 millionths, and (-24) + (+32) = +8 millionths

Column 12 (Temp. in column 6 - Reference temp)(Concrete coefficient of thermal expansion)
(70.60 - 70.00)(5.5) = -3 Negative because it is subtracted from the strain
(74.30 - 70.00)(5.5) = -23 Negative because it is subtracted from the strain

Column 13 (Value in column 11) + (Value in column 12)
(+4) + (-3) = +1 millionths, and (+8) +(-23) = -15 millionths

* Data supplied by Gage Manufacturer.

(prepared by WES)

Plate 2-13

______________ PROJECT

JOINT METER DATA SHEET

Joint meter No. ______________________________ Sheet ________

Location ______________________________

Calibration data:

Meter resistance at 0 * ° F.......... 50.16 * ohms.
Change in temperature per ohm change in resistance.......... 11.10 * ° F.
Ratio in closed position.......... 96.79 %.
Original calibration constant.......... 0.00046 * in./.01 % ratio change.
Calibration constant corrected for leads.......... 0.00051 in./.01 % ratio change.
Resistance of leads at 70 ° F.......... 6.30 ohms (pair).

1	2	3	4	5	6	7	8	9	10
Date	Time	Total resist., ohms	Lead ohms	Meter resist., ohms	Temp., ° F.	Resist. ratio, %	Change in ratio, %	Indicated movement, inches	Remarks
2-5-80	8 am	62.85	6.30	56.55	70.9	96.79	0	0	concrete setting, joint closed
2-6-80	8 am	63.08	6.35	56.73	72.9	96.77	-0.02	-0.0010	
2-7-80	8 am	63.65	6.51	57.14	77.5	96.77	-0.02	-0.0010	

EXAMPLE CALCULATIONS

Column 1 Self explanatory

Column 2 Self explanatory

Column 3 Total resistance of meter as measured in the field. This reading is taken directly from the readout box (with selector switched to resistance) and includes resistance for both meter and associated lead cable.

Column 4 The resistance of the lead wires when disconnected from the meter, or if the leads are connected to the meter, measure resistance between the red-white terminals and between the red-black terminals. Sum these two resistances and subtract the sum from the resistance between the black-white terminals. If the meter has a 4-conductor cable it can be read directly.

Column 5 (Value in column 3) - (Value in column 4)
62.85 - 6.30 = 56.55, 63.08 - 6.35 = 56.73, 63.65 - 6.51 = 57.14

Column 6 The temperature reading of the meter is calculated by subtracting the calibration meter resistance (usually that at 0°F) from the meter resistance in col. 5 and then multiplying by the change in temperature per ohm change in resistance.
(56.55 - 50.16)(11.10) = 70.9, (56.73 - 50.16)(11.10) = 72.9, (57.14 - 50.16)(11.10) = 77.5
If the calibration temperature is not 0°F then the above calculated temperature is added to the temperature at which the meter was calibrated.

Column 7 Reading as taken directly from the test set (with selector switch set to ratio) if the ratio is greater than 100%, some instruments assume the presence of the hundreds column and only measure XX.XX

Column 8 (Present value of column 7) - (Ratio in closed position)
96.79 - 96.79 = 0, 96.77 - 96.79 = -0.02, 96.77 - 96.79 = -0.02

Column 9 (Value in column 8)(Calibration constant corrected for leads)
(-0.02)(0.00051) = -0.0010

* Data supplied by Gage Manufacturer.

(Prepared by WES)